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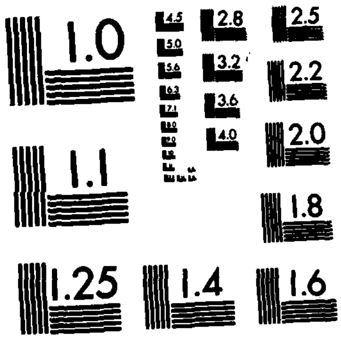

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Monterey, California

THESIS

SYNTHESIS OF A COLLISION TOLERANT
FIXED NAVIGATION MARKER SYSTEM

by

Max R. Miller Jr.

October 1982

Thesis Advisor: J. F. Sladky

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#20 - ABSTRACT - (CONTINUED)

It is the intent of this work to develop a data base, investigate the use of mathematical/computer models, develop a configuration matrix of installation modes.

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Synthesis of a Collision Tolerant Fixed Navigation Marker System

by

Max R. Miller Jr.
Lieutenant Commander, United States Coast Guard
B.S., California Maritime Academy, 1971

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
October 1982

Author: ______________________

Approved by: ______________________ Thesis Advisor

______________________ Second Reader

____
Chairman, Department of Mechanical Engineering

____
Dean of Science and Engineering

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NOMENCLATURE

A_p	Piling Projected Area (immersed)
A_m	Area of Navigation marker
C	Distance from the Neutral Axis to Outermost fiber of beam
C_{Dp}	Drag Coefficient (Piling)
C_{Dm}	Drag Coefficient (marker)
D	Outside Diameter
d	Inside Diameter
D_p	Diameter of Piling
E	Young's Modulus
F_{Dc}	Force on Piling Due to Current
F_{Dm}	Wind Force on Navigation Marker
h	Thickness
I	Moment of Inertia
J	Mass Moment of Inertia
K	Stiffness
l	Length
L	Length of Test Section
L_p	Length of Piling (immersed)
M	Mass
M_c	Moment Due to Current
M_T	Total Moment Due to Environment
M_{wm}	Moment Due to Wind Loads on Marker
M_{wp}	Moment Due to Wind Loads on above Water Piling

R	Mean Radius
Re	Reynold's Number
S	Distance from Applied Wind Load to Flexure Element
U_w	Wind Speed
U_∞	Water Free Stream Velocity
ν	Kinematic Viscosity
ρ_1	Water Density
α	Angular Deflection from Vertical Axis

I. INTRODUCTION

Since the early 1700's when the Little Brewster Island Lighthouse was erected to light the entrance of Boston Harbor, the United States Coast Guard has expanded the short range aid to navigation system to include Alaska, Hawaii, east and west coasts of the mainland United States and major inland rivers and lakes.

The U.S. Coast Guard is wholly responsible for 60% of the approximately 80,000 short range aids to navigation. This includes procurement of material, fabrication, installation, maintenance, repair, and replacement. This system of short range aids consists of buoy and fixed structures which offer a combination of sound, light, and/or electronic beacons.

The dependability of these markers is critical as they identify hazards to marine traffic. The markers define navigable channels in rivers and are extensively used by pilots in guiding barge traffic. Not only must these aids be there but their position must be known and correspond to the navigation charts. Figure 1 illustrates the approximate distribution and densities of the navigation aids throughout the United States.

In order to meet this mission requirement the U.S. Coast Guard maintains a fleet of highly specialized vessels varying in length from 33 feet to 180 feet. These specialized vessels

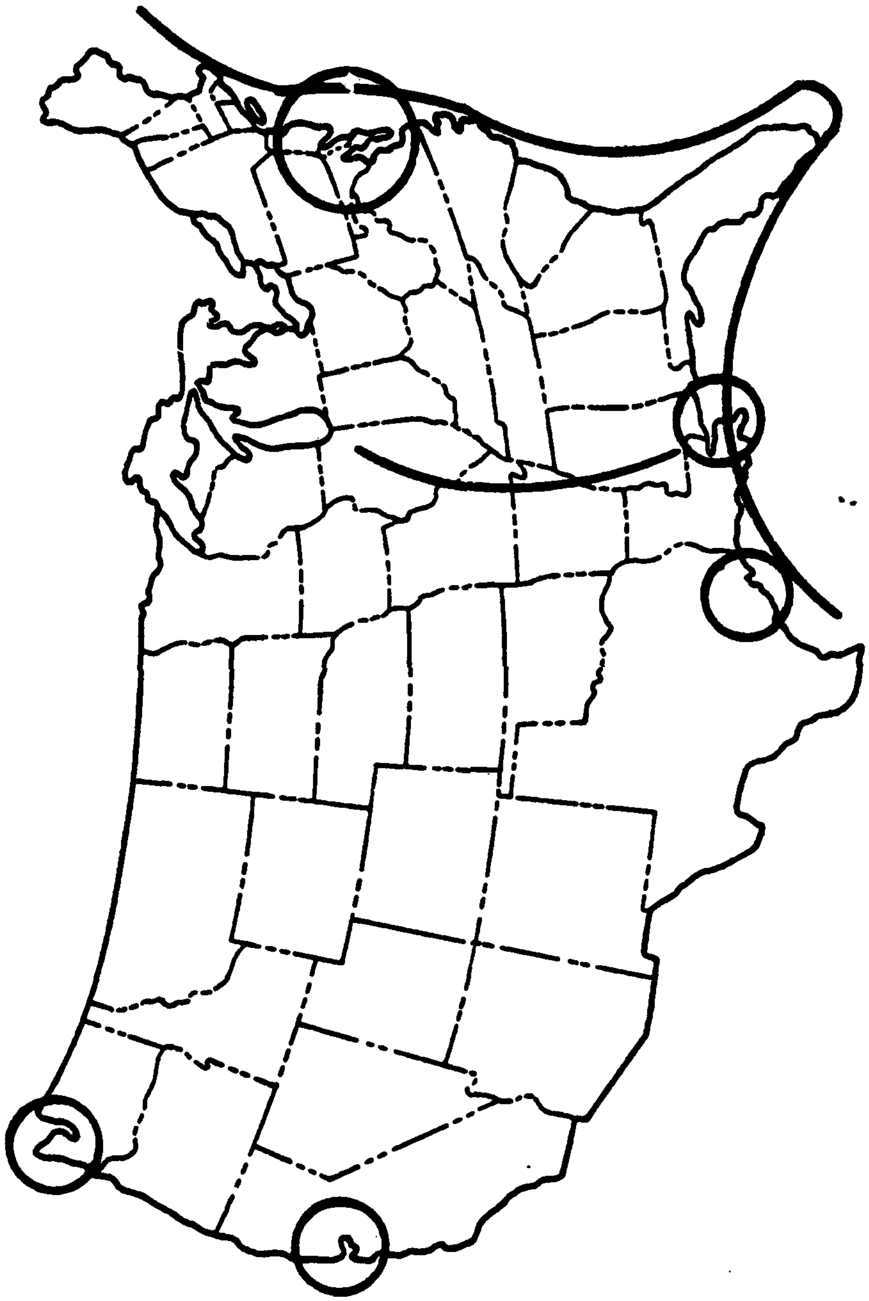


Figure 1. Distribution of High Density Marker Locations

carry crews whose technical background and capability must span many different disciplines including civil, mechanical, and electrical engineering. Equipment as diverse as 4500 lbf. diesel powered pile drivers and delicate alignment instruments are utilized.

The navigational aids are designed to withstand the environmental loading due to wind, current, waves, and ice where applicable. In addition to the above loads many markers, especially in narrow channels, are often exposed to direct collision impact loads by marine traffic such as ships, and barge strings. According to the 8th U.S. Coast Guard District, Civil Engineering Branch, located in New Orleans, Louisiana, approximately 300 fixed structure aids are "destroyed" each year. Another 400 fixed aids are damaged. In that district alone the direct replacement cost exceeds $1,000,000.00 annually. This includes vessel time, man hours, materials, and navigation packages. The installation of a navigational marker is particularly labor intensive. In each operation the precise marker location must be identified, the damaged structure located and pulled, and a new fixed structure driven. In addition the possibility of law suits and litigation due to marker failure can represent significant additional cost to the government.

It is thus obvious that a navigational structure that will maintain its position and orientation under environmental loads yet absorb or deflect under vessel collision impact would significantly alleviate the effort and cost required to maintain the system.

It is the purpose of this study to explore the feasibility of a "Collision Tolerant" (CoTo) fixed navigation marker that will significantly reduce costs and improve the system's reliability. In order to accomplish this the project is structured in four phases. The first will focus on the environmental conditions and the resultant environmental loads on a typical fixed structure. The second phase will address concept formulation. The third element will focus on analytical modeling and experimental validation of a flexure joint. The last phase will be devoted to the system integration.

II. PROBLEM STATEMENT

During its life cycle a fixed navigational aid sees a combination of two categories of loads; environmental loads and collision loads. Failures due to environmental conditions alone are very rare. Destruction as a result of collision impact loading is the primary cause of failure in fixed aids. Collision may completely destroy the marker including its supporting structure, or it may disable its signaling capability. In the former case not only is the marker destroyed but also its precise location is lost. It may be several days before a report is received by the U.S. Coast Guard identifying the damaged aid. Once it has been identified, a buoy tender is dispatched to first find the original position of the navigational aid, remove damaged aid if necessary, and drive the necessary piling to support a new navigational aid package.

Approximate costs of replacement vary depending on location and size of the navigational aid. Also factoring into the total cost is the size of vessel required to effect repairs. The exact replacement costs are difficult to estimate. For a simple driven pile structure the costs vary between $500.00 and $2,500.00 for wood pile and a light steel structure respectively. Vessel cost ranges over a wide spectrum but for convenience $400.00/hour is assumed. A typical installation, where the location of the marker must be determined and surveyed, may require 8 to 10 hours. Thus the cost of complete replacement may be as high as ten thousand dollars.

It is thus obvious that a navigation marker which has the capability to survive an encounter with a vessel will significantly affect the total cost of the system. Figure 2 represents the performance constraints and operating conditions of a fixed navigation marker.

A. Environment	East & Gult Coast
Maximum Water Depth	20 Feet
Minimum Water Depth	5 Feet
Wave Action	4-5 Feet
Maximum Wind Speed	75 Miles/Hour
Ice Conditions	N/A
Bottom Conditions-Slope	10-15 Degrees
-Consistency	Soft-Clay
Current	1-3 Knots
B. Performance Tolerance	
Small Deflection (Environmental Load)	No Damage
Small Deflection (Impact Loading)	No Support Damage
Full Run-Over Capability	Nav. Aid Damage
Allowable Variation In Recovery	15 Degrees
C. Installation	
Driving Loads	4500 lbf
Special Handling Requirements	
-Maximum Weight	18000 lbs
-Maximum Length	60 Feet (wood) 40 Feet (Steel)
Lifecycle 10-20 Years	
D. Materials	Wood Steel Concrete
E. Maximum Cost	$10,000.00

Figure 2. System Performance Parameters

III. MARKER LOADING CONDITIONS

The type of loading conditions are depicted in Figure 3. There are 3 categories: environmental, installation, and collision. These loading conditions will be largely determined by the geographic location of the marier. In addition, bottom topography and soil conditions will be a factor in the type of marker system structure loads. Bottom terrain can vary between coral, gravel and/or dense sand, loose sand and/or clay, and fibrous silt. Slope conditions generally encountered range from flat to 15 degrees.

The relationship between current conditions, type of bottom, piling diameters, and driven depth has been developed through experience and empirical correlation. A typical driven piling performance chart is presented in Figure 4 taken from Reference 1.

A. ENVIRONMENTAL LOADS

Environmental loads can be grouped into four categories: current loads on the piling, wind loads on the superstructure, loads due to ice conditions, and loading due to vortex shedding by the immersed piling. Figure 5 presents a typical marker loading condition.

1. Current Loads

In determining the current loads on a vertical piling a number of assumptions are made. a) The current is assumed uniform and constant with depth. In reality there is a

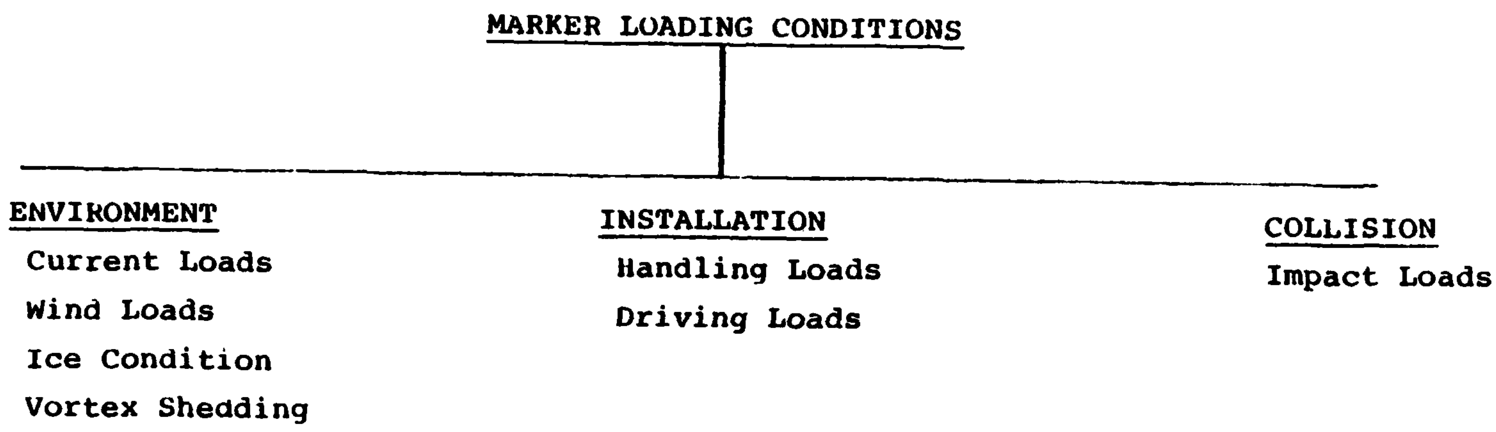


Figure 3. Marker Loading Conditions

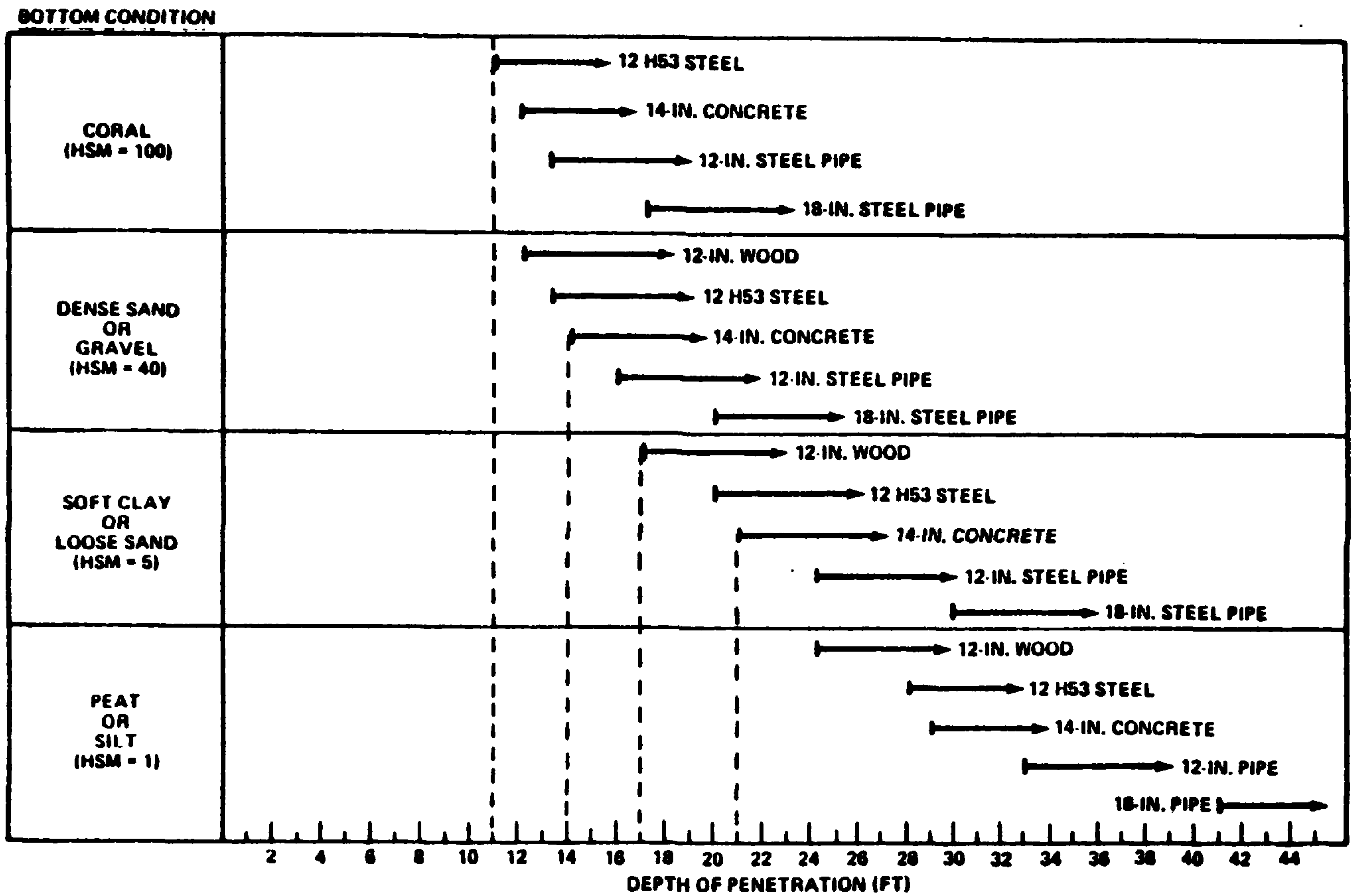


Figure 4. Driving Depths for Various Pile Types [Ref. 1 pp.4-8]

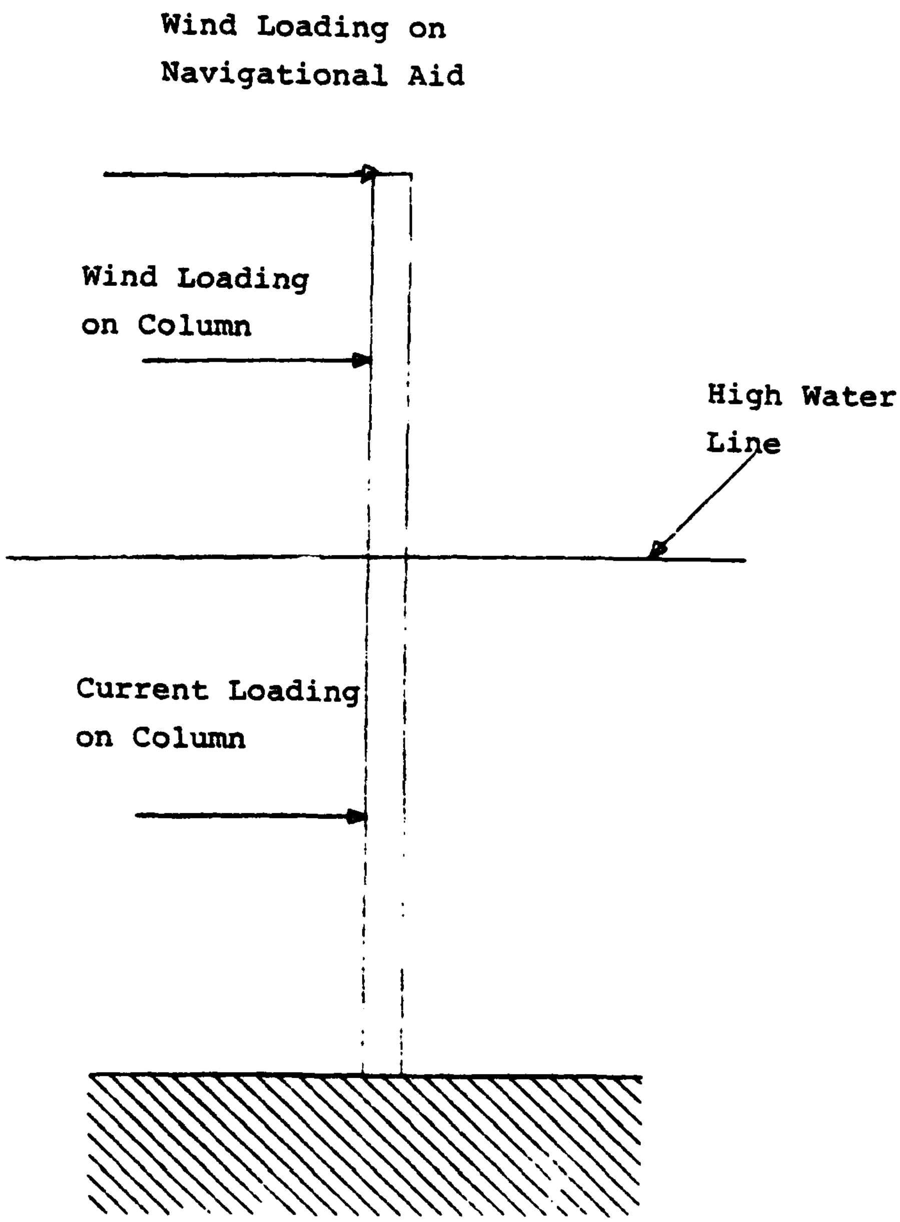


Figure 5. Typical Loading Distribution

certain velocity stratification, however, this variation is difficult to determine. The above assumption is considered reasonable as it is on the conservative side. b) In the case of an incline piling the current load will be determined on the basis of a vertically projected length of the piling. This is again a conservative approach often followed in ocean engineering practice.

The drag on a circular cylinder transverse to a fluid stream is given by Equation 1.

$$F_{DC} = \frac{1}{2} \rho_{\ell} U_{\infty}^{2} A_{p} C_{Dp} \tag{1}$$

where C_D is the drag coefficient for the appropriate Reynolds number, A is the cylinder's projected area, U_∞ is the current velocity, ρ is the density of the fluid. The moment generated at the bottom of the piling due to the current load is given by Equation 2.

$$M_C = \frac{L}{2} F_{DC} = \frac{1}{4} \rho D_p L_p^2 U_\infty C_D \tag{2}$$

For the case where the piling is inclined α degrees from the vertical then the second assumption above is applied. In this case the piling length in Equation 2 becomes $L_\alpha = L_p \cos\alpha$. Examination of Equation 2 reveals that the piling moment due to current forces is linearly proportional to the pile diameter D_p and varies as the square of the immersed length L_p.

2. Wind Loads

The wind loads are primarily evident on the superstructure or the navigation marker proper. In addition, air loads are also developed on the above-water piling. In the majority of cases the navigational signal marker is a flat plate approximately 9 square feet in projected area. For this geometry the drag is given by Equation 3.

$$F_{DM} = \frac{1}{2} \rho U_w^2 A_M C_{DM} \quad (3)$$

The moment thus becomes

$$M_{wM} = S F_{DA} \quad (4)$$

The wind loads on the above-water portion of the piling itself are given in a similar fashion to Equation 1, as:

$$F_{Dw} = \frac{1}{2} \rho U_w^2 A_p D_{Cp} \quad (5)$$

The moment thus becomes

$$M_{wp} = (L_p + \frac{L_p - S}{2}) F_{Dw} \quad (6)$$

As the system departs from a vertical orientation both of these wind loads will tend to decrease.

3. Ice Conditions

Ice conditions will certainly impact the design of fixed navigation structures. The consideration is formulated in two parts; floating ice and accumulated top side ice. In the former case there can be two possible situations. The ice can exist as a frozen drifting sheet, or ice chunks, floating with the current. A drifting ice sheet moving on a frozen-over body of water will, if of sufficient thickness, destroy the fixed piling structure or push it over. Ice sheets floating with the speed of the current will introduce impact loads.

Top side ice accumulation on the navigation marker itself is difficult to quantify. Suffice it to say that weight correction factors can be applied. For the purpose of this study ice effects are not considered. First there is little marine traffic in frozen-over conditions and hence little use for the correctly displayed markers. Second ice impact loads are in effect analogous to collision loads from marine traffic. Thus a system that can handle traffic impacts can survive collisions with moving ice flows.

4. System Frequencies

In order to insure that the system's natural frequency f_n does not correspond to the frequency with which vortices are shed, the vortex shedding frequency n is related by the Strouhal number, Equation 7.

$$\frac{n\ D_p}{U_\infty} = S \quad \text{(Strouhal number)} \qquad (7)$$

Ideally, the natural frequency should have the following relationship.

$$f_n \geq 1.5\ n \qquad (8)$$

If the structure is modeled as a rigid body attached to a torsion spring, the equation for the natural frequency is given by Equation 9.

$$f_n = \frac{W_n}{2\pi} \qquad (9)$$

where

$$W_m = \left(\frac{K}{J}\right)^{1/2}$$

and

$$K = \frac{EI}{\ell}$$

$$J = M\underline{r}^2$$

For the purpose of this design a worst case loading situation will be assumed. Thus the particular structural configuration must maintain its vertical orientation within specified limits for the case where the moments due to current and wind loads are in the same direction. It is realized that this concurrence of applied loads will exist only in a few instances.

B. INSTALLATION LOADS

Installation loads fall into two separate categories: handling loads and driving loads.

1. Handling Loads

Handling loads are the forces introduced during ship loading and unloading of the system and in positioning the marker for driving. While this aspect may not be of great significance in the case of a single piece piling it will need to be considered when the system includes possible flexure elements.

2. Driving Loads

In the conventional single piling system driving loads are not a problem. Any proposed system must have the capability to handle the driving hammer's force which can approach 4500 lbf.

C. COLLISION LOADS

Impact loads as a result of collision between marine vehicles and/or ice conditions and those encountered in pile driving can either heel over the structure or completely break it off. It is difficult to quantify the range of impact loads generated by these collisions.

IV. CONCEPT FORMULATION

In order that a fixed navigation marker "survive" under the loading conditions described it must have certain attributes. These are:

a) Under environmental loads of current and winds the marker must maintain a vertical orientation within a certain angular envelope. Under these loads the system must be "stiff".

b) On impact by a barge the piling must become very "soft" and deflect out of the path of the vehicle. The deflection may continue even to the point that the marker is "run over" by the traffic.

c) Once the impact loads are removed the marker must automatically redeploy into its vertical orientation envelope. The above requirements are described with the aid of Figure 6. Depicted are the desirable reaction moments of the system and the loading moments due to environmental forces and impact versus the deflection α. Up to a maximum worst case moment due to environmental loads the piling must maintain a vertical orientation within $\pm 15°$. If a moment greater than the design moment is applied, such as that resulting from impact, the piling must deflect, i.e., the angular excursion becomes very large. This deflection allows the piling to clear the impacting object.

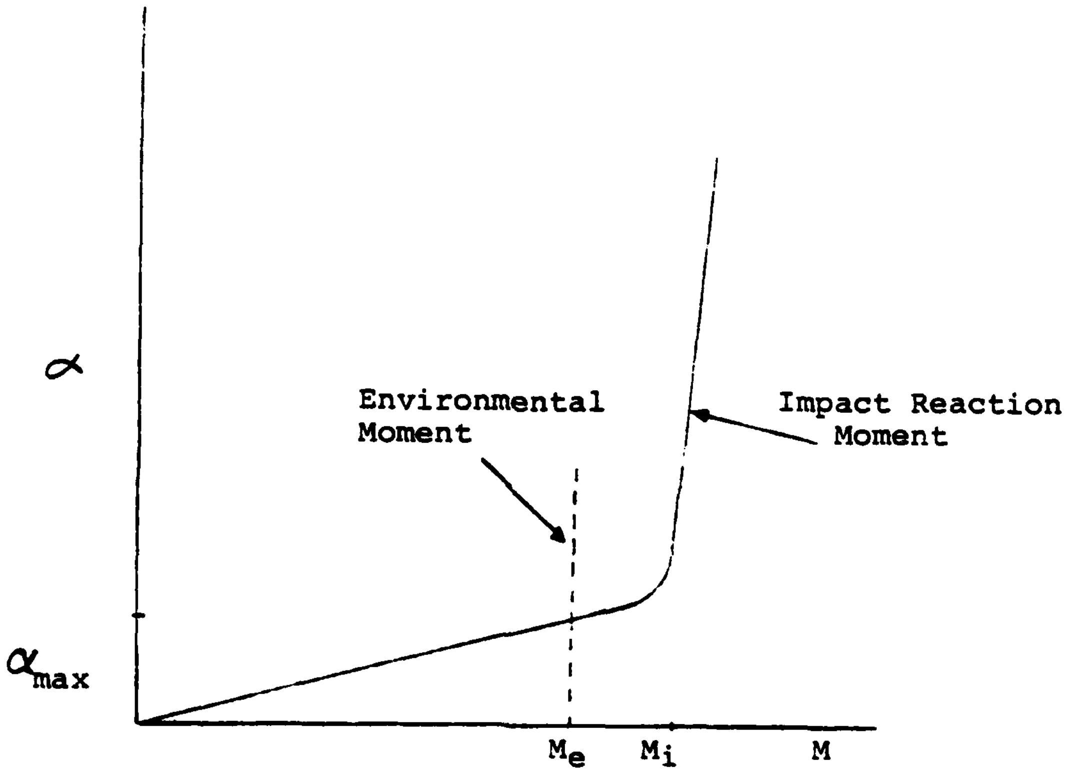


Figure 6. System Behavior Characteristics

Once the traffic has overrun and cleared the area the restoring moment must exceed the moment due to environmental forces present in the deflected configuration. Otherwise the system will not regain its original vertical deployment. It is thus apparent that a type of "snap through" behavior is required of this piling. This in turn leads into a search for a flexure mechanism that will have the desired characteristics.

A range of concepts was examined. A selected set of arrangements is illustrated in Figures 7 through 10. Each has its advantages and disadvantages. Different types of flexure elements include torsional springs, mechanical snap-through mechanism (similar to the common wall mounted light switch), tethered floating platforms, and rubber elements. The United States Coast Guard Office of Ocean Engineering, Washington, D.C., for reasons of low cost and high off-the-shelf availability decided that rubber in a particular configuration had significant promise. The most common configuration of these rubber elements is a hallow circular cross section of various outside to inside diameter ratio. The rubber is either extruded with no attached flanges or molded with integral metal flanges. Appendix A is a sample of commercial literature available on this material.

These units, generally referred to as cell marine fenders, are designed as annular columns which fail in the buckling mode. For the proposed application in the case of the fixed navigational system the cylindrical rubber element will

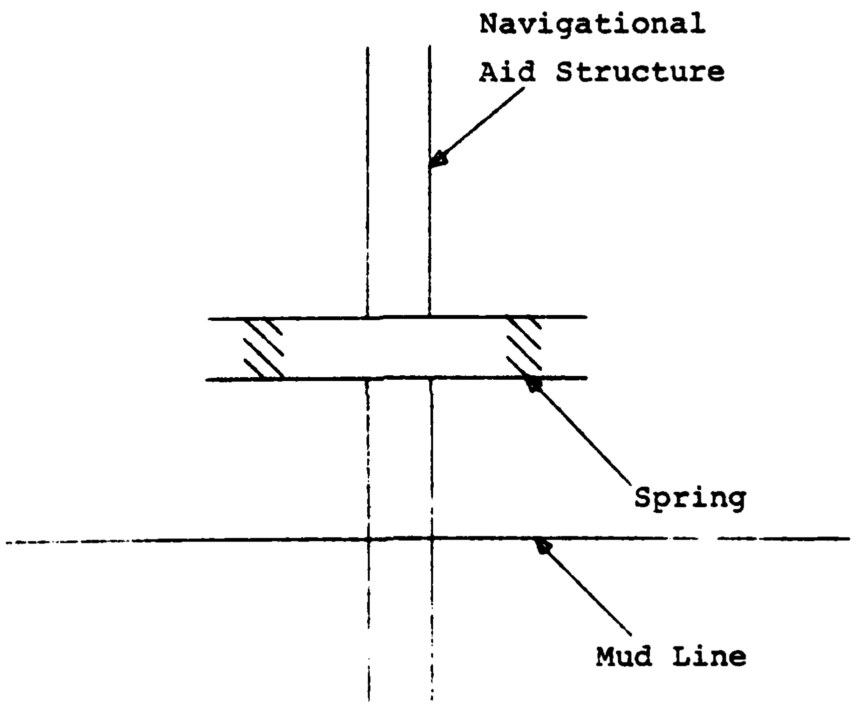


Figure 7. Spring Flexure Element

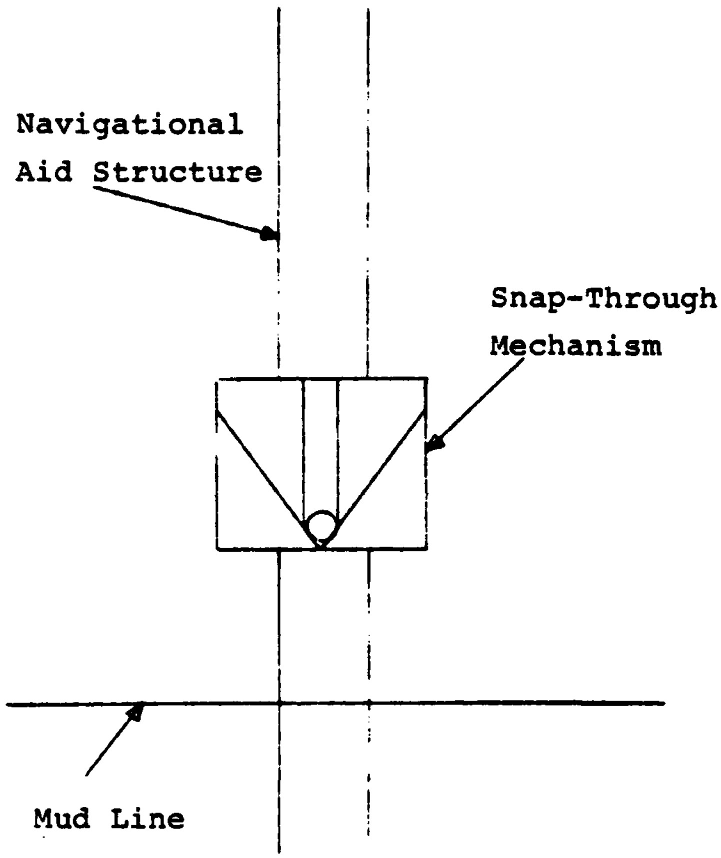


Figure 8. Snap Through Flexure Element

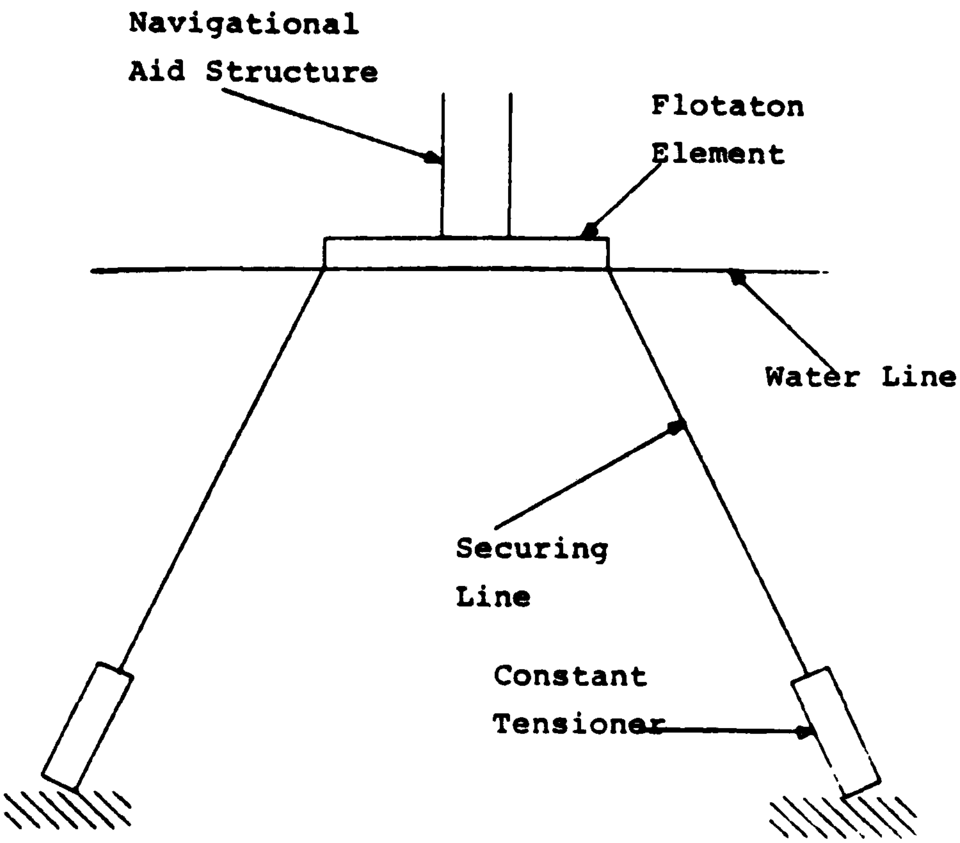


Figure 9. Tethered Floating Platform

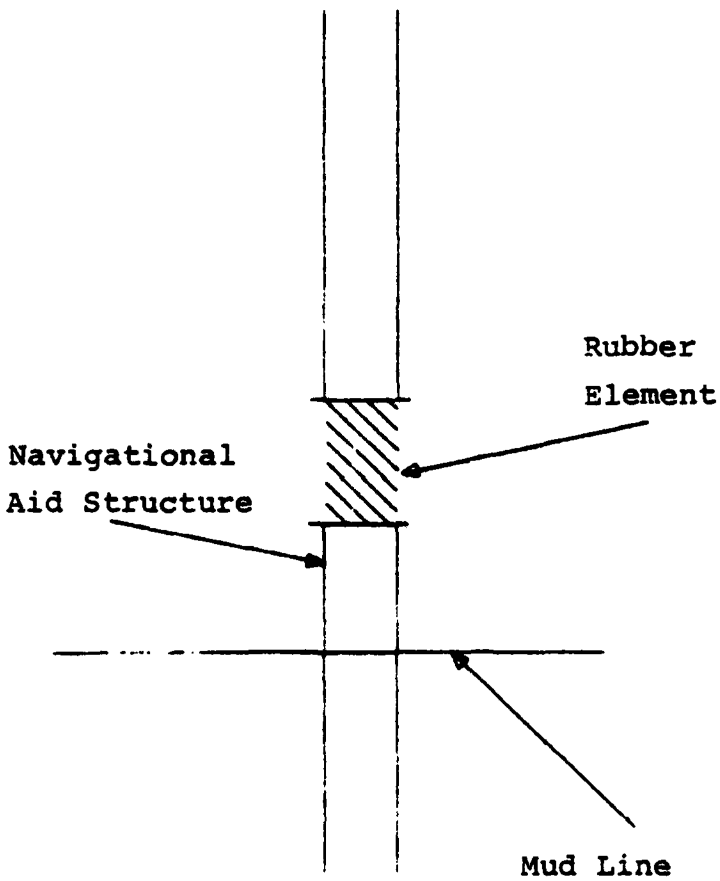


Figure 10. Rubber Flexure Element

serve as a flexure pivot. In the near vertical or on-design orientation the element will serve as a cylindrical beam.

V. MODEL DEVELOPMENT

The purpose of this section is to develop an insight and gain understanding into the behavior of a rubber cylindrical beam. The loading conditions assumed are similar to those that would be found if the beam were used as the flexure joint in the fixed marine piling.

A. ANALYTICAL APPROACH

The type of loading and expected reaction loads in the proposed system is illustrated in Figure 11. The primary steady loads are the moments due to environmental forces. These are: current loads on the piling, wind loads on the navigation marker, and wind loads on the above water piling. The dominant load is the current load. The transient or collision impact loads will of course be magnitudes larger than the steady loads.

The analysis of the CoTo system was modeled as a simple cantilever beam of circular cross section (pipe). As indicated in Appendices B and C, the various loads when acting in parallel with one another create the free body diagram noted. The linear differential equation relating the deflection v to the internal bending moment M in a beam is

$$\frac{d^2v}{dx^2} = \frac{-M}{EI} \tag{10}$$

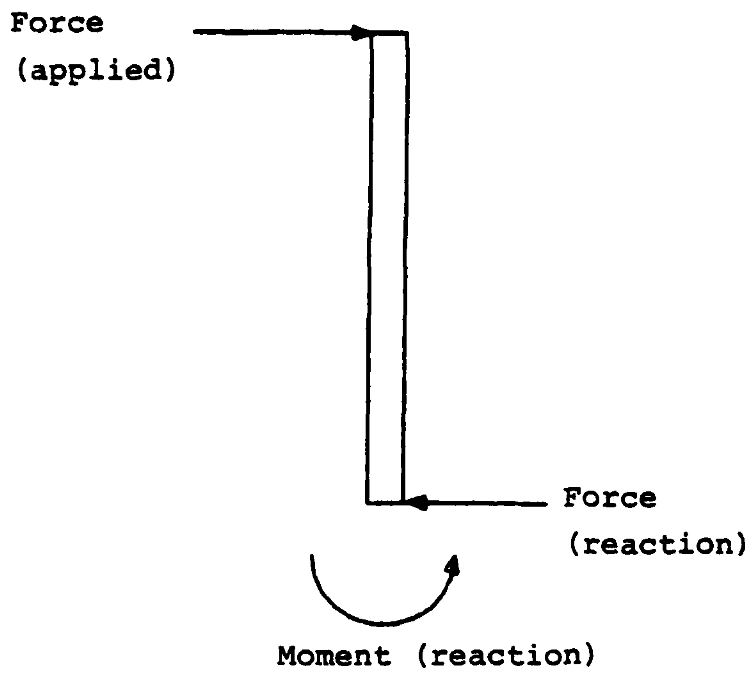


Figure 11. Free-Body Diagram

where X is the axial coordinate and EI is the flexural rigidity or bending modulus. For small angles, less than 5 degrees, θ will be approximately equal to the slope of the curve ($\tan \theta$). The deflection v and the slope of the deflection curve are related by

$$\frac{dv}{dx} = -\theta \qquad (11)$$

Assuming loading intensity w can be related by

$$\frac{dV}{dx} = -w \qquad (12)$$

and

$$\frac{dM}{dx} = V \qquad (13)$$

The following set of useful differential equations is formed

$$\left.\begin{aligned} \frac{dv}{dx} &= -\theta \\ \frac{d\theta}{dx} &= \frac{-M}{EI} \\ \frac{dM}{dx} &= V \\ \frac{dV}{dx} &= -w \end{aligned}\right\} \qquad (14)$$

[Ref. 2, p. 331]

These equations are called the equations of flexure for the bending of a beam. Appendix D shows the solutions of these differential equations for a fixed-free beam.

These relationships generally apply to isotropic materials which when loaded below critical values produce only small deflections (rotations < 5°). Analysis of a beam with isotropic material properties relies on the linear relationship of stress to strain

$$\{\sigma\} = [E]\{\varepsilon\} \tag{15}$$

Analysis of a beam with nonisotropic and nonlinear materials uses the nonlinear relationship

$$\{\sigma\} = [E(\varepsilon)]\{\varepsilon\} \tag{16}$$

However for very small deflections of rubber the classic methods of analysis can be used with reasonable results.

Because Hooke's Law of Proportionality between stress and strain does not hold for strains as large as are common with rubber, the modulus of elasticity is seldom used in the rubber industry.

As was indicated, bending of this beam is a very critical parameter in determining the failure mode of the model. Considered also is the snap-through action which occurs past certain deflection limits. This is similar to the onset of thin shell buckling. At this point, it must be noted that there is no buckling "per se" in the large deflection of the beam that is loaded with transverse forces. However, as the cylindrical beam deforms, local buckling does occur when the original circular cross section collapses. Equation 17 relates the critical load for a geometry similar to the proposed configuration

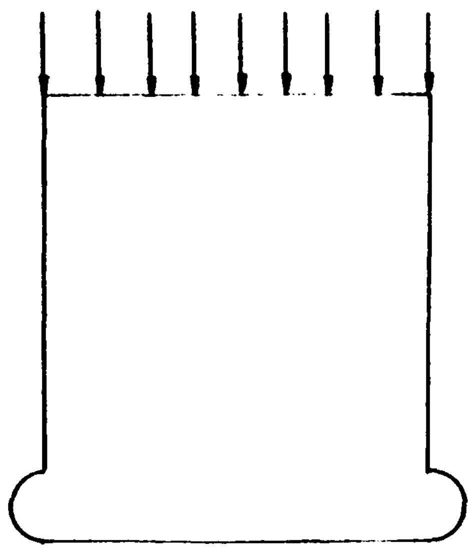
$$P_{cr} = - \frac{Eh^2}{R[3(1-\nu^2)]^{1/2}} \tag{17}$$

[Ref. 3, pp. 151]

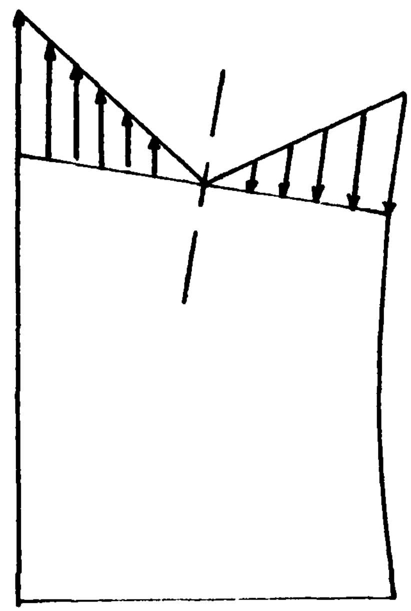
for the onset of thin shell buckling loaded axially as shown in Figure 12a. Loading of the model and identification of the "local buckling" zone is shown in Figure 12b.

The validity of Equation 17 relies on uniform axial loading and a D to d ratio approaching unity. Because the experimental model does not conform to either of these constraints Equation 17 will be of no value to predict the point of failure.

It was thus decided to approach the problem employing computer programs using finite element techniques. It was hoped that these codes would have the capability to address the configuration, and material in question. Two different computer codes were explored: GIFTS (Graphics-oriented Interactive Finite element Time-sharing System developed at the University of Arizona by Professor Hussein A. Kamel) and ADINA (A Finite Element Program for Automatic Dynamic



a) Axially Loaded Thin Shell



b) Model Loading

Figure 12.

Incremental Nonlinear Analysis developed by Klaus-Jurgen Bathe at the Massachusetts Institute of Technology.

1. GIFTS

The GIFTS program is a particularly useful code in addressing a wide variety of structural problems. Details of the GIFTS model used in this analysis are contained in Appendix E. Because GIFTS does not contain nonlinear analysis options, results achieved were not very encouraging and the program's use was not pursued further.

2. ADINA

ADINA was developed for the purpose of analyzing highly nonlinear systems due to either material nonlinearities and/or geometric nonlinearities. Details of the ADINA model are presented in Appendix F. The program output yields realistic results particularly in the small deflection range. It is the Adina code that was used to analytically predict deflections for the proposed flexure element.

B. EXPERIMENTAL CORRELATIONS

In order to validate the results of the ADINA model an experimental test program was designed and executed. A model rubber flexure joint was installed and tested throughout a wide deflection range. Loads and the resulting moments were related to the angular deflection of the system.

A schematic of the test apparatus is illustrated in Figure 13. A photograph of the flexure unit under test is presented in Figure 14. As shown, the testing apparatus fixes one end

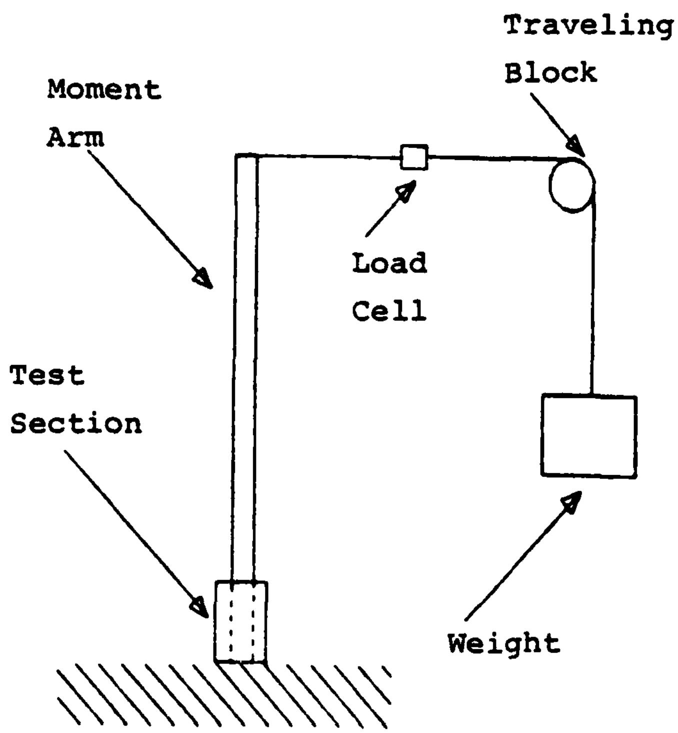


Figure 13. Schematic of Test Apparatus

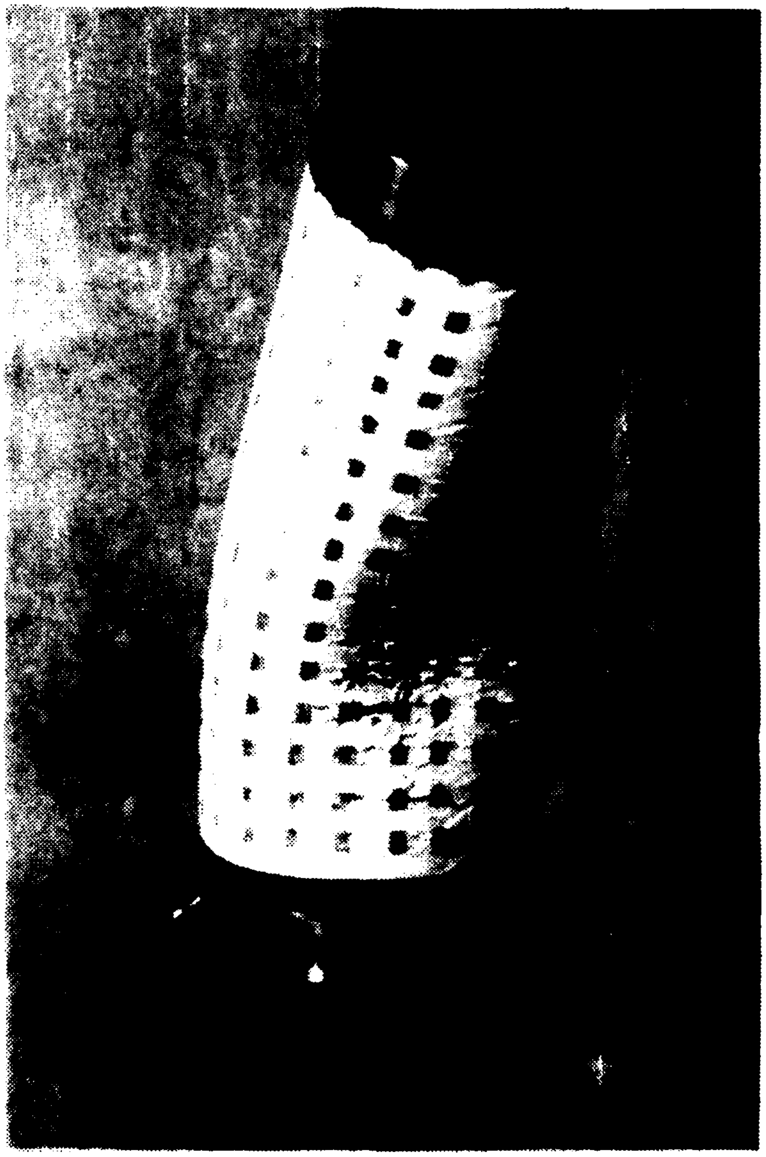


Figure 14. Element Test Section

of a beam and applies a known load transversely to the free end. The load remains perpendicular to the beam by means of a traveling block. As the load is applied and the beam deflects the slope of the beam is measured in degrees by an inclinometer fixed to the beam.

Two extruded rubber cylinders, 5 ft. x 5 in. (OD) x 2.5 in. (ID) of ASTM D-2000 grade rubber were purchased. The test cylinders were machined to outside diameters varying from 5 to 2.75 inches. Ratios of length to outside diameter were independently established at 2:1, 1:1, and $\frac{1}{2}$:1. This was accomplished by varying the insertion depth of the upper attachment fixture of the test apparatus. Appendix G is the tabular presentation of the results.

Figures 15a through 15f is a series of photographs depicting the progressive deformation of the flexure joint as increasing load is applied. It is evident that up to a certain angular deflection (Figure 15c) the geometry of the system remains circular. At a certain point the rubber cylindrical element begins to ovalize and the critical moment of inertia starts to decrease. This is shortly followed by complete geometric failure and extremely large angular deflections (Figure 15f).

The details of the experimental variables and pertinent physical dimensions are presented in Figure 16.

C. DISCUSSION

In evaluating the experimental results and comparing them to the results of the computer model it is first

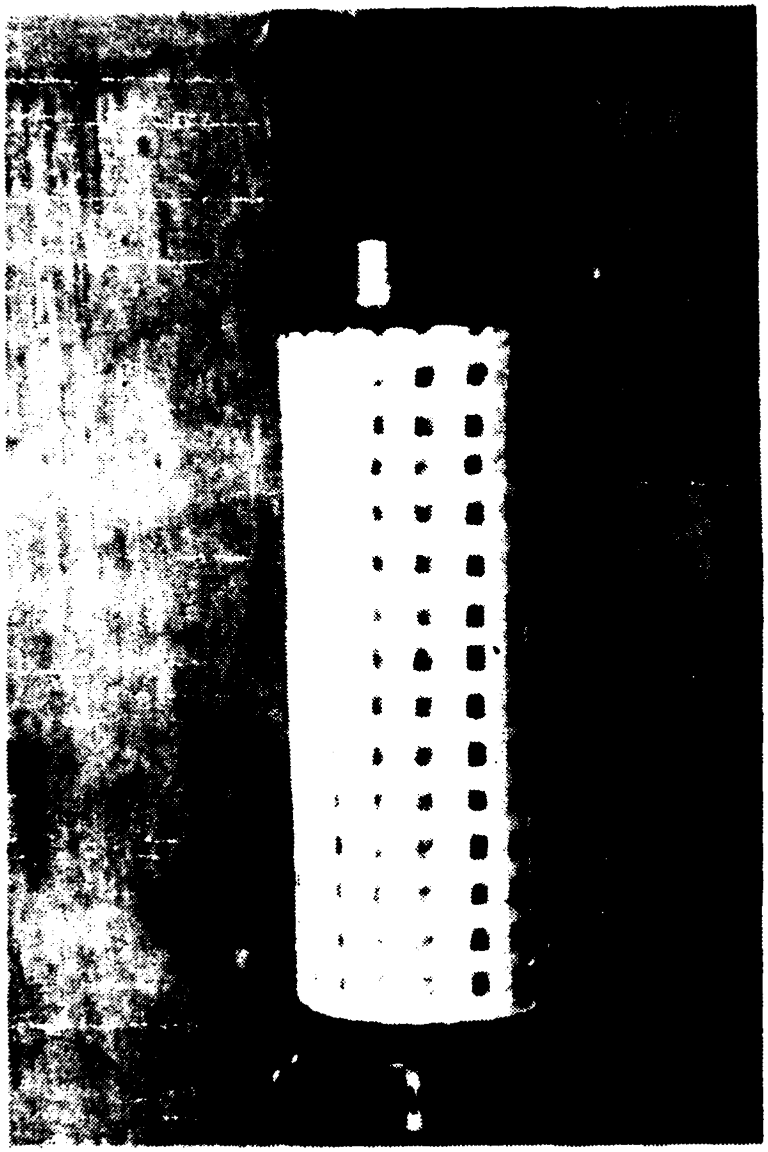


Figure 15(a)

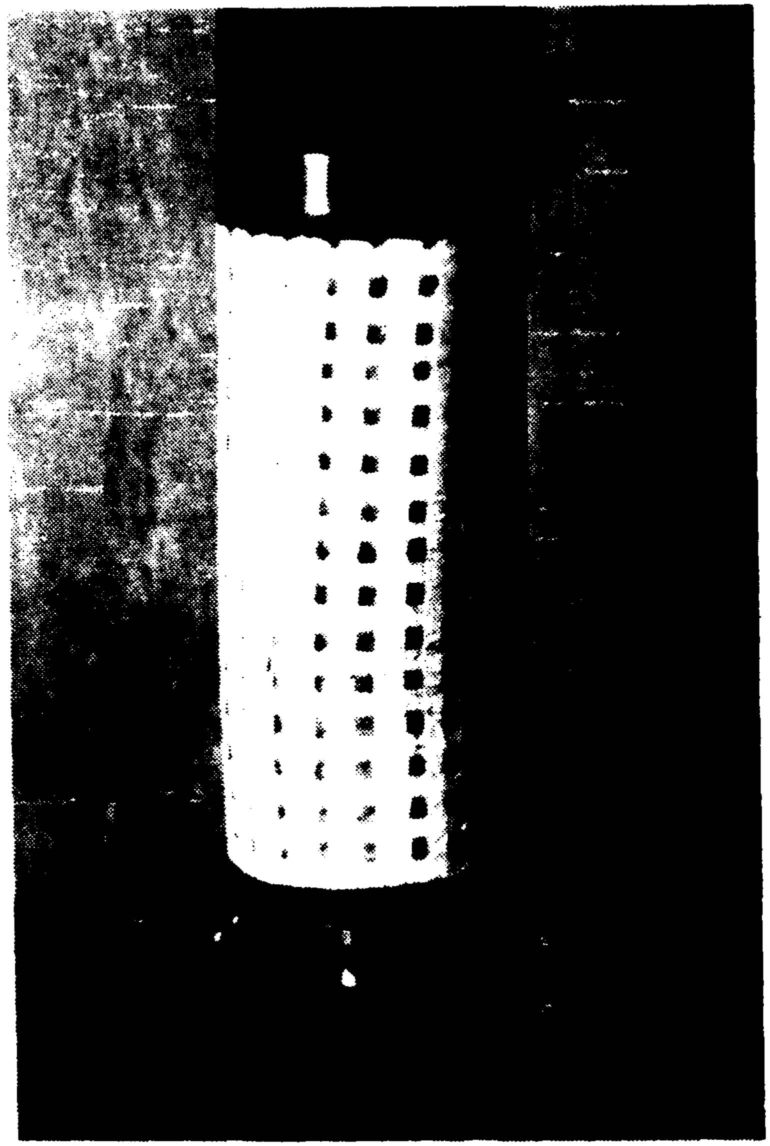


Figure 15(b)

Figure 15. Test Section Bending Sequence

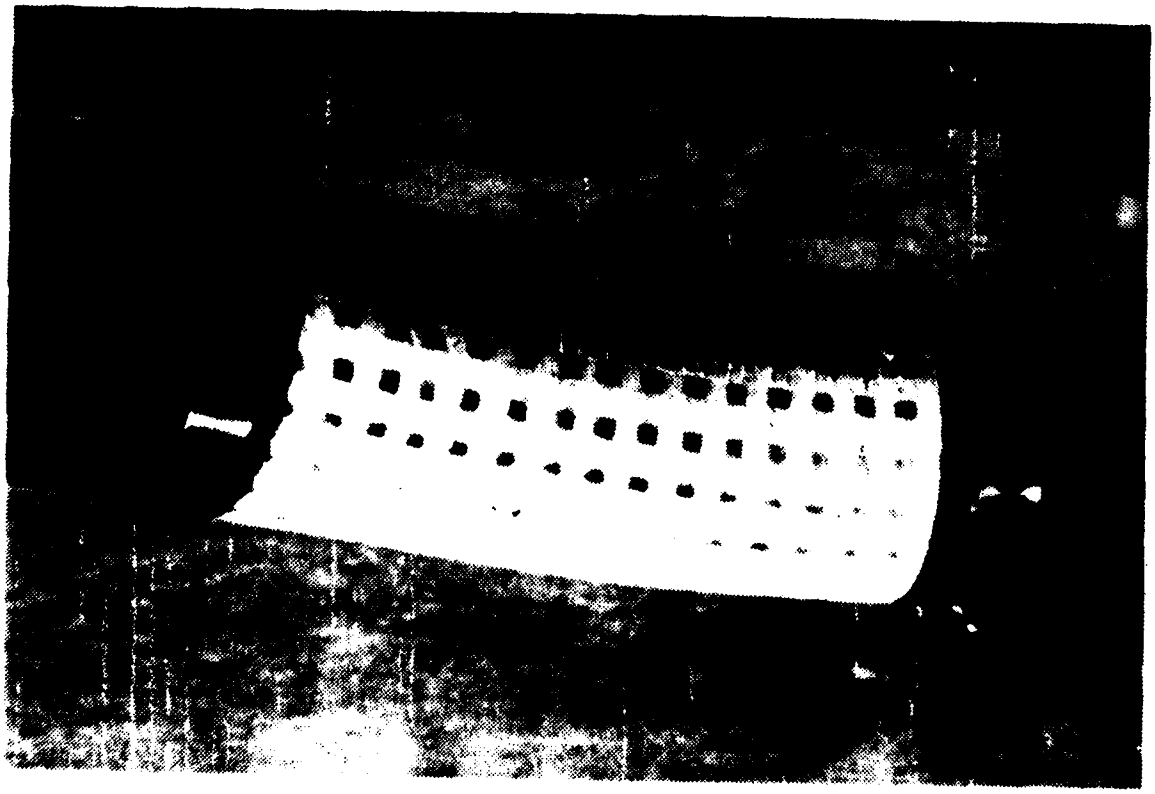


Figure 15(c)

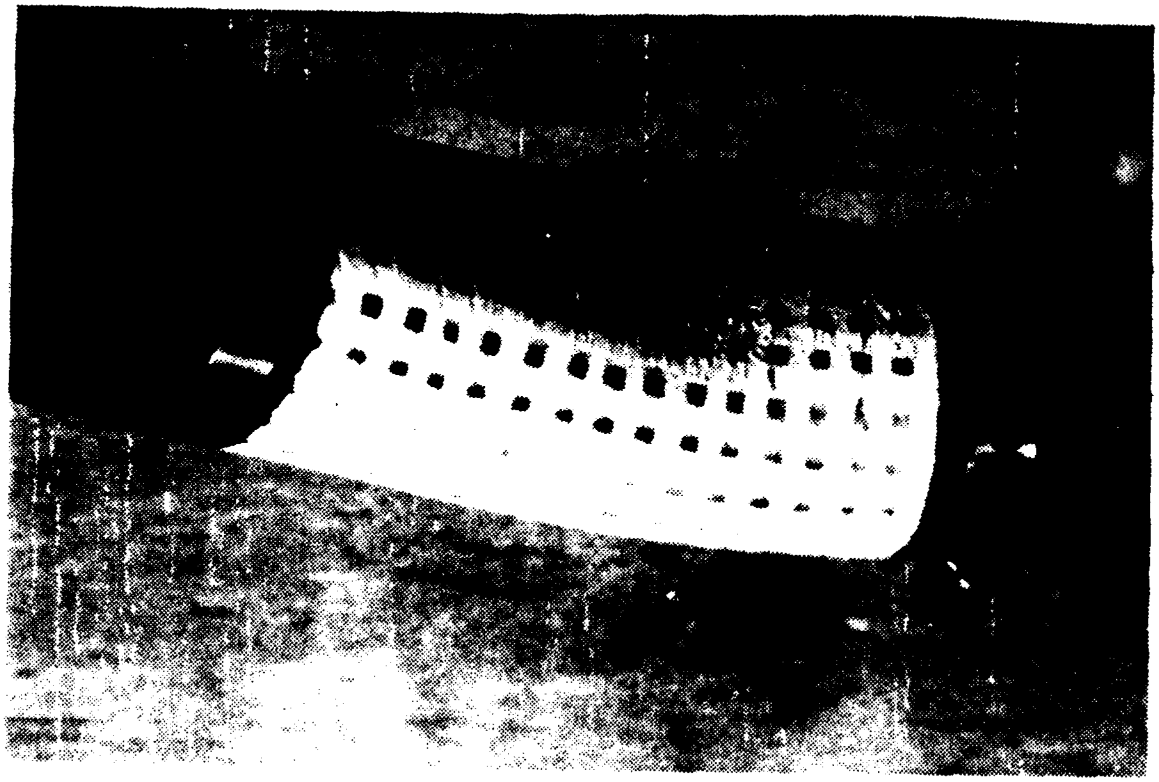


Figure 15(d)

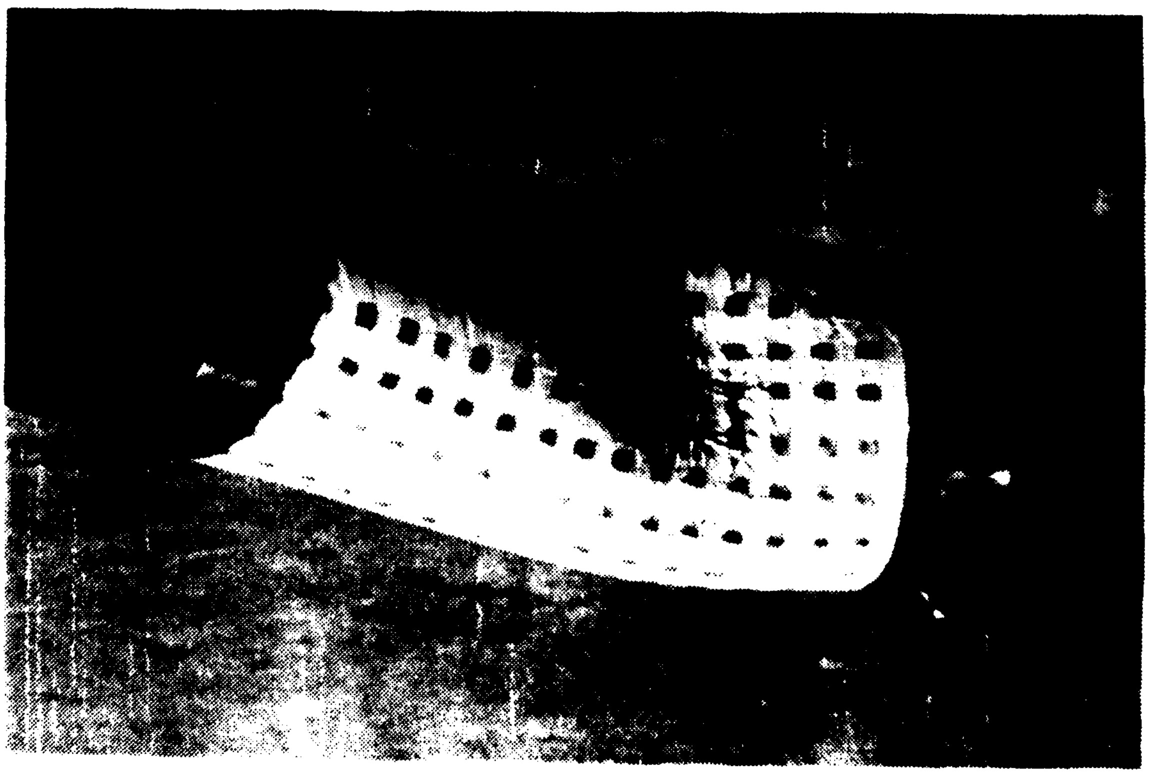


Figure 15(e)

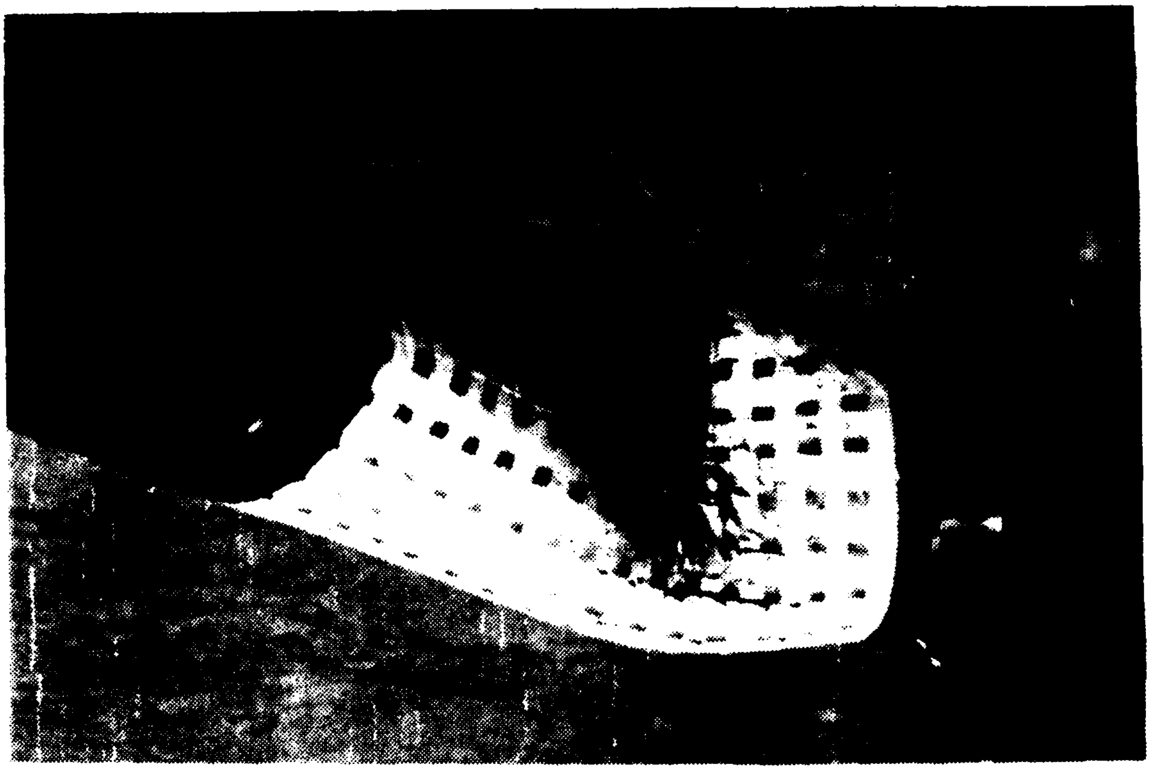


Figure 15(f)

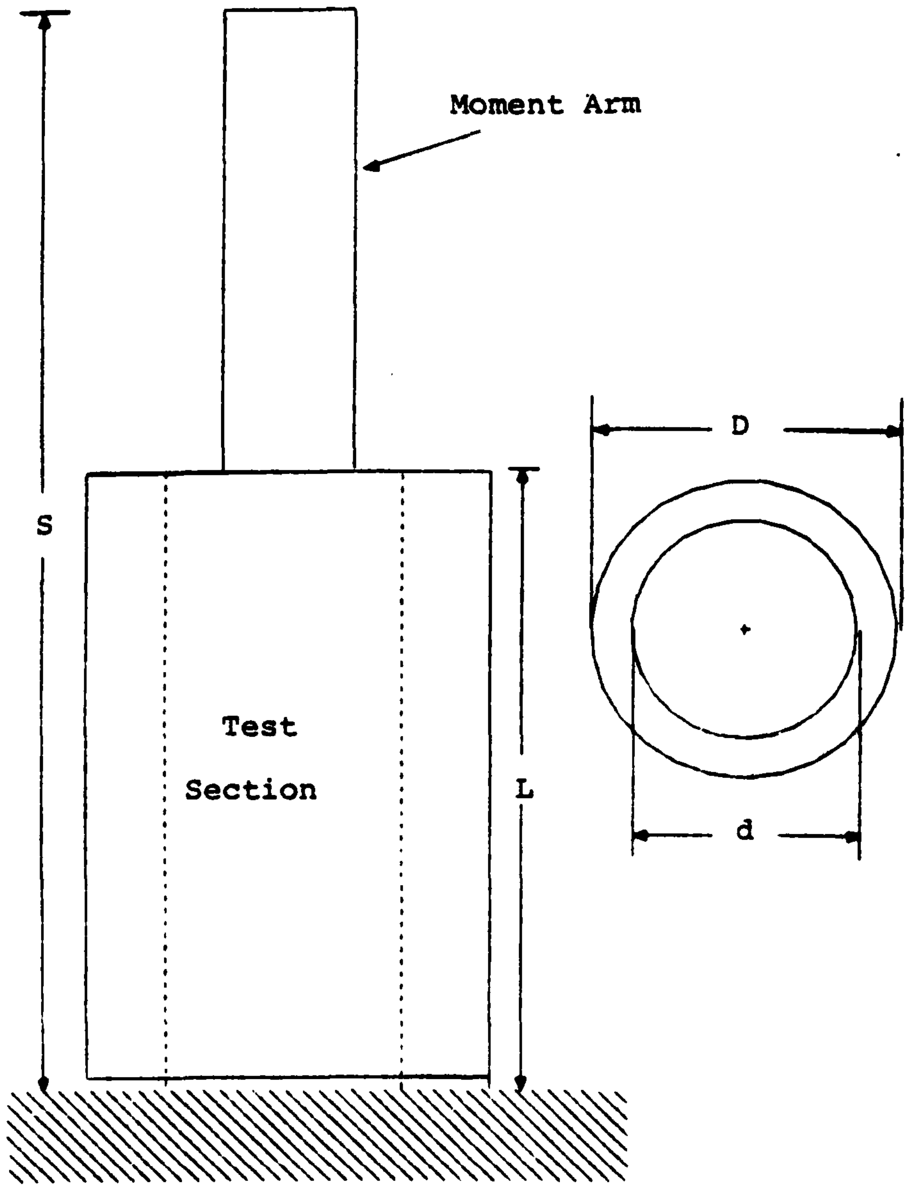


Figure 16. Test Section Dimensions

necessary to review possible avenues by which error may influence the outcome.

In the experimental model, two significant areas appear to introduce error. First, wall thickness variations of the test samples and second, creep of the material through the attachment or clamping mechanism.

The extruded rubber cylinders purchased for the experiment have a ±10% wall thickness tolerance. This corresponds to existing rubber industry standards for extruded geometries. The test samples were machined from these standard units. The machining operation and the available quality of the final surface cuts did not allow for precise control of the rubber sleeve wall thickness. For the thinner wall sections, i.e., 1/8 inch, the final cut roughness may have introduced variations on the wall thickness of up to 10%. In the thicker section samples this variation would have decreased.

The second probable source of error appears to have been the rubber test jig attachment point. The fastening system used to secure the loaded moment arm inside the test section and to fix the bottom end of the unit utilized 9/16 inch stainless steel hose clamps. As the test section was deflected by the applied load, up through 10°-15° no appreciable creep through the clamps was noticed. This was confirmed by releasing the load and allowing the test material to regain its original position. Beyond 10°-15° inclination, creep through the clamp introduced as much as 7° residual inclination with respect to the original unloaded case. This error became more pronounced as the wall thickness was increased. Thus, on this basis, deflections at the very high angles are not likely to be very reliable. This may not pose a serious problem in the design phase as at this level of deflection the rubber cylinder has buckled and other, more drastic, phenomena are involved.

In the case of the ADINA modeling, two possible sources of error exist. In the first instance there are inherent limitations in the formulation of the ADINA program. While ADINA program is structured for "rubber" type materials, it is limited to 2-dimensional plane stress problems only. In order to model the test section, a 3-dimensional circular beam element was used in conjunction with an elastic-plastic material model. The choice of these two options was the closest available combination of models to the actual conditions.

As a result it is expected that ADINA will yield realistic results up to 10° or 15° of beam deflection. Beyond this point the material is part the range of validity of the computer's material properties.

The second source of error arises as a result of the aspect ratio (length/diameter) of the structural member. The computer models a cantilever beam. As such the implied limiting length/diameter ratio is ideally in the range of 10:1. The actual geometry of the cylinder in question has a maximum length/diameter ratio of 2:1 and more closely resembles a short stubby beam than a long cantilever.

Figure 17 presents the results of a typical output from the ADINA program. It is observed that as the D/d increases, in the case of increasing wall thickness, the slope of the moment vs. deflection curves decreases. It is also seen that as the length/diameter ratio L/D increases the initial stiffness decreases. These trends are as one would expect. However, the key observation to be made is that the ADINA program does not predict the "snap-over" behavior expected in large deflection.

The experimental test program is summarized in Figure 18. In all cases progressive loading was maintained to deflections in excess of 40°. For the thin wall geometries, i.e., D/d $\simeq$ 1:1 to 1:1.26 there was a definite "snap-over" phenomenon observed. This trend was not evident for relative thick walled cylinders, i.e., greater than 1:1.26. The system continued to deflect without any evidence of discontinuity.

In the case of small L/D ratios, approximately .5, the flexure system developed a "lockup" characteristic. This is best described with the aid of Figure 19. As the system is loaded, inside edges of the sample holder pinch the sample material. The outside edges are furthest apart and place the sample material in tension. Beyond this point deflection of the system is "locked up".

It is thus apparent that the flexure geometry that will exhibit the desirable characteristics will involve relatively thin walls, (D/d) near unity, and have length/diameter ratios, (L/D), in excess of 1:1.

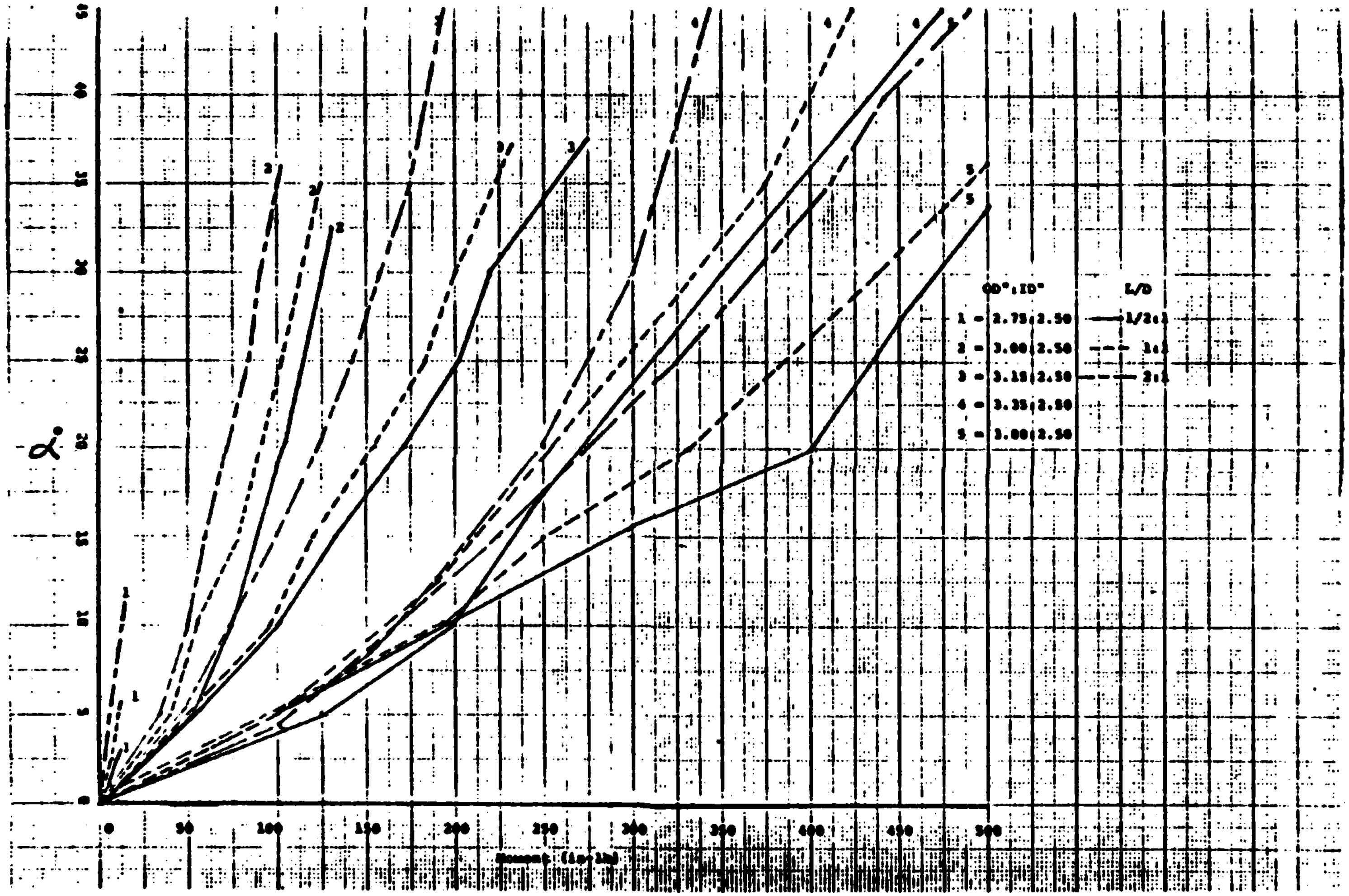


Figure 17. ADINA Output

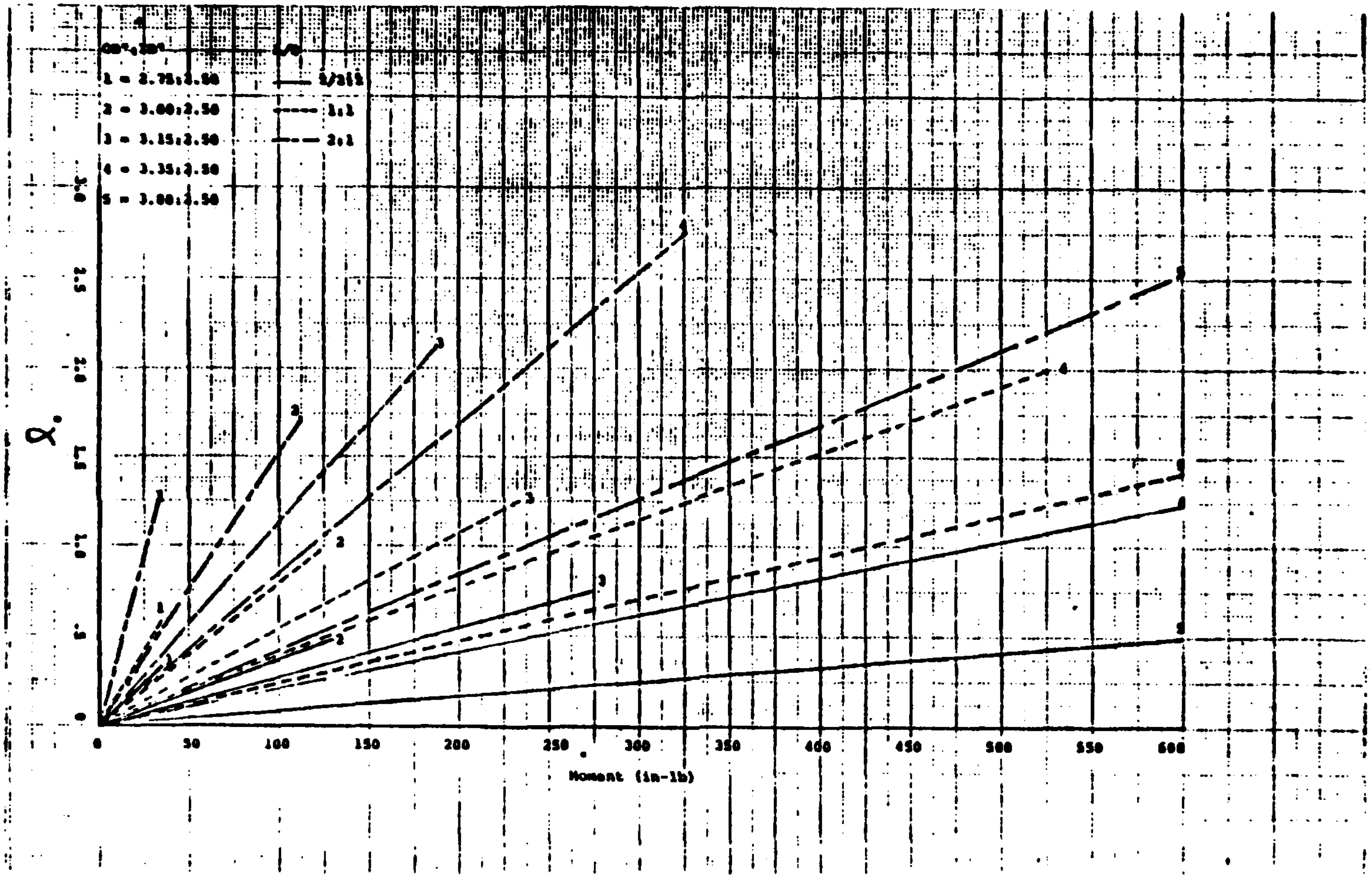


Figure 18. Experimental Test Data

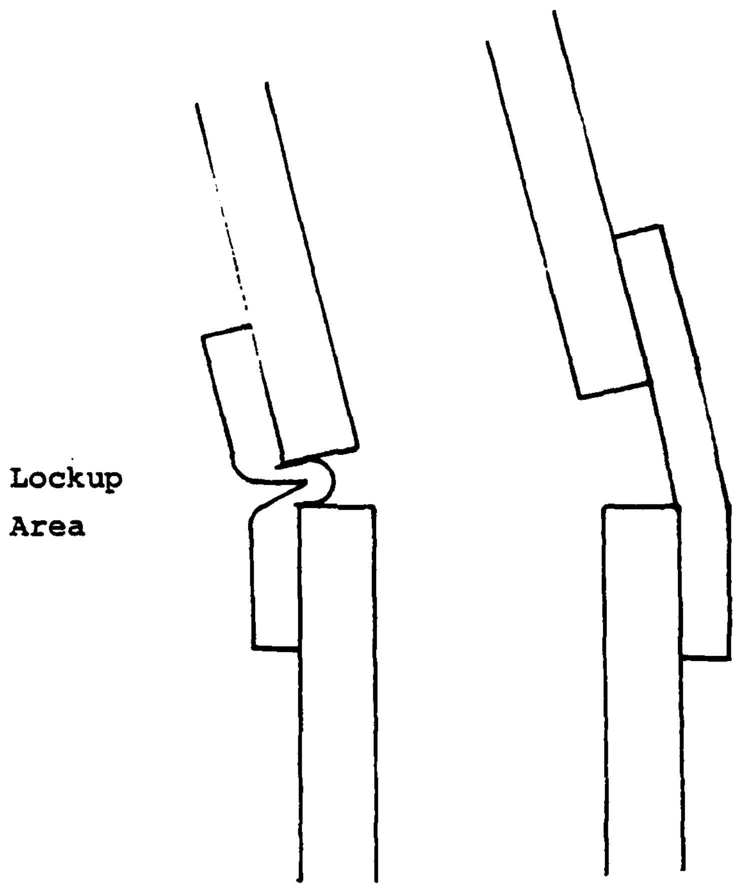


Figure 19. Lockup Characteristic

Figure 20 depicts a comparison between the ADINA theoretical results and the experimental test on a sample where $D/d = 1.26$, and $L/D = 2$. Excellent agreement is evident through a deflection of 10°. Past this point the trends diverge. Three distinct zones are evident in the experimental results. The first, the small deflection zone is consistent with the ADINA predictions for all geometries. The second zone involves a change in the moment/deflection curve slope but the geometry is still relatively axisymmetric. The third zone involves a rapid geometric adjustment which in turn results in large deflection.

It appears that the change of the characteristic slope in Zone II is the result of incipient buckling. It is difficult to precisely identify and explain the behavior in this phase as the geometry is continually adjusting and in fact different sections of the rubber material may be in either the elastic or plastic ranges.

In the completely collapsed mode, illustrated in Figure 21, the geometry has adjusted such that the circumferential walls fold over and form a nominal rectangular cross section. The width of this section is $\pi D/2$ and the thickness is $2t$, where t is the original tube wall thickness. In the fully deflected range, i.e., high α, the element will fail in the buckling mode. Figure 22 depicts both initial bending and buckled geometry.

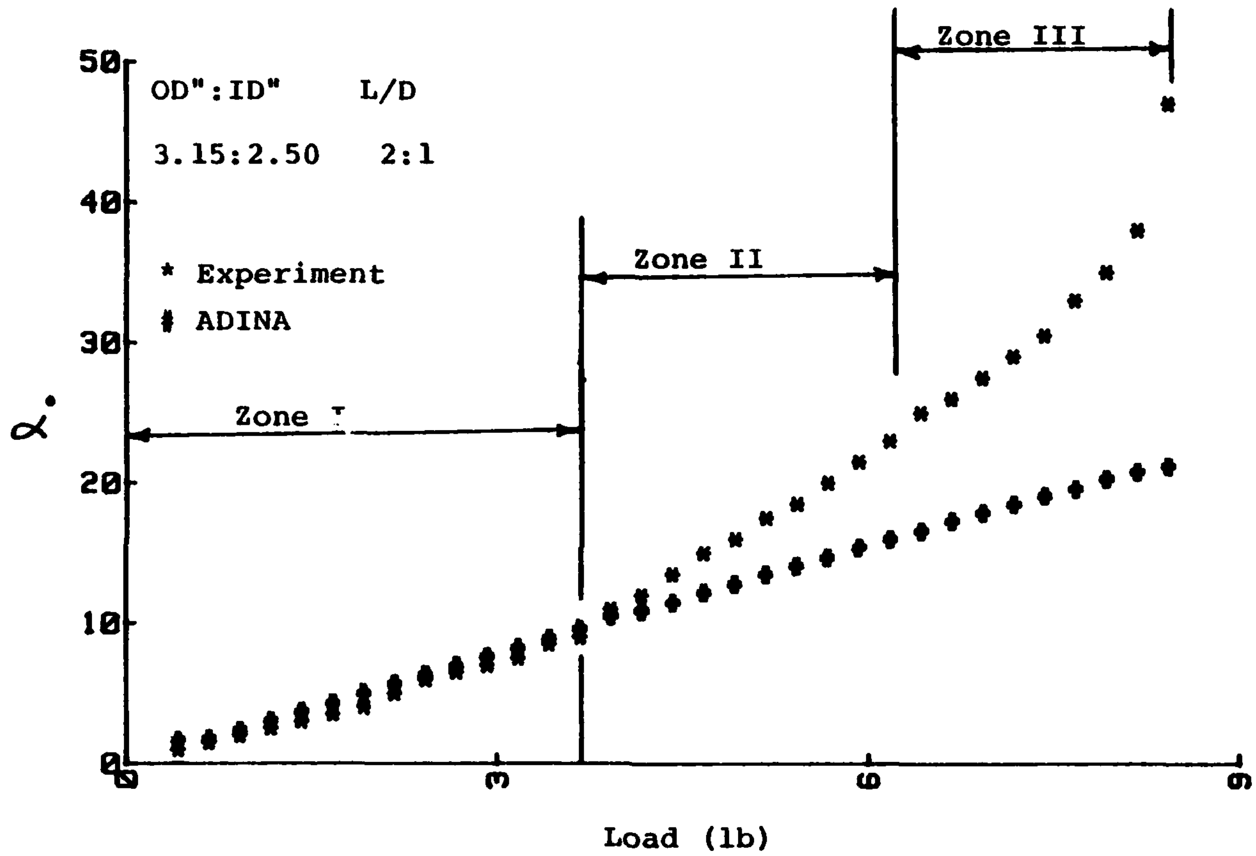


Figure 20, Comparison of Experimental Data and ADINA Output

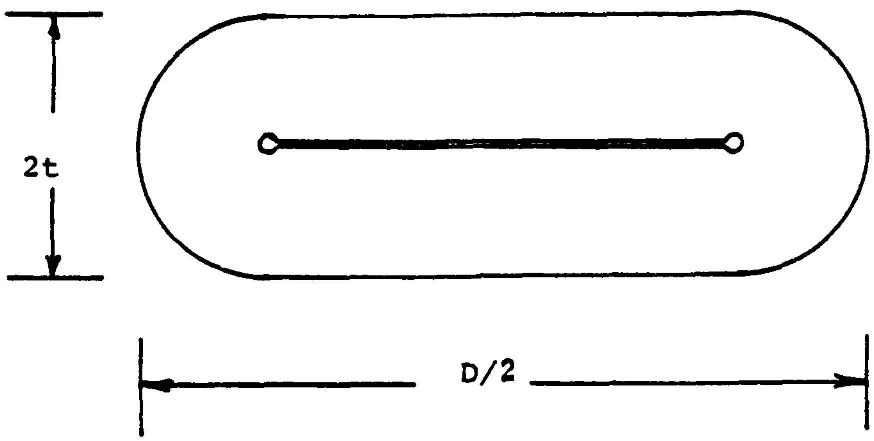


Figure 21. Collapsed Test Section

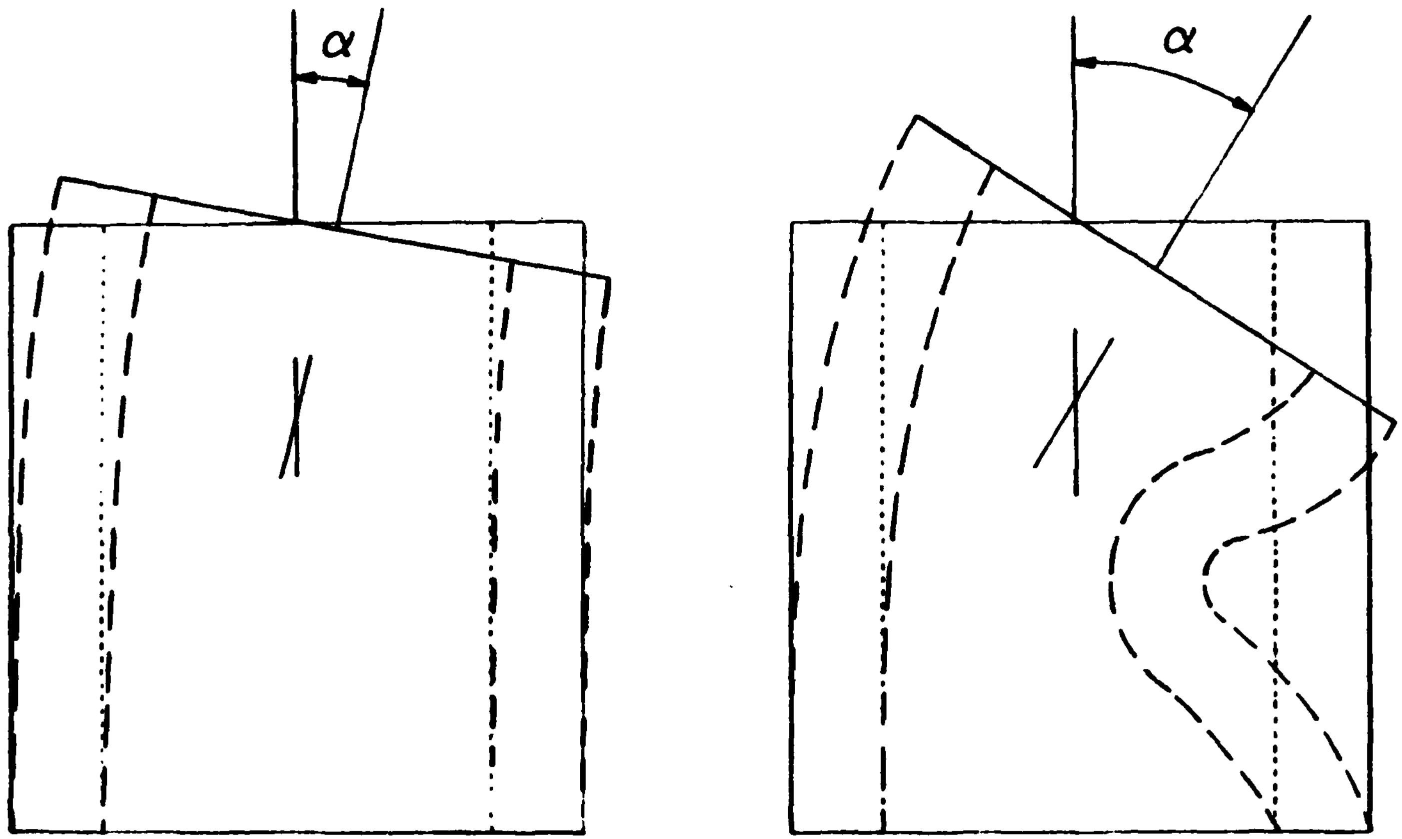


Figure 22. Buckling and Bending Mode

VI. DESIGN SYNTHESIS

The synthesis of the final configuration involved the trade offs of a large number of variables. Some of these were quite straightforward and quantifiable while others tended to be qualitative in nature and difficult to define.

Additional constraints were placed on the project by the U.S. Coast Guard that were more operational in nature. These include:

a) Installation, maintenance, and removal of the CoTo marker system must be accomplished without the use of divers or sophisticated underwater instrumentation.

b) The proposed CoTo system must not impose serious departures from present practices of pile fabrication and installation.

c) The proposed CoTo system must fit within the capability of existing vessels and service platforms and must not require highly specialized handling and tooling equipment.

In review of the operational requirements of the CoTo marker system:

a) Maintain vertical orientation with ±15 degrees under specified environmental (wind and current) loading conditions.

b) Fold or "snap-over" when greater loads (such as vessel collision) are applied.

c) Regain vertical orientation within ±15 degrees when collision loads are removed.

Thus there are two separate key loading conditions; the environmental loads which must be countered by the flexure joint reaction and the collision loads that result in the snap-over action of the system. In the case of the environmental loads a worst case design philosophy is followed. It is assumed that the current and wind loads will act in the same direction and have maximum values. For this situation to arise on site would require that all current, wind, and frontal orientation of the navigation marker be all in the same direction; a highly unlikely circumstance.

A. ENVIRONMENTAL LOADS

1. Current Loads

It was observed from Equation 2 that the piling loads due to the current are directly proportional to the piling diameter and increase as the square of the piling length (L^2). In order to minimize the loads on the rubber flexure system it would be desirable to have a minimum diameter and minimum length for the section of the piling above the flexure joint.

2. Wind Loads

The wind loads and the resulting moments generated on the flexure element are essentially constant. Variation in the worst case moment depends only on the physical distance between the nav marker proper and the flexure point.

From these considerations it is evident that the flexure point itself be located as near the surface as possible.

The piling diameter above the flexure should be as small as possible consistent with other loading conditions, i.e., top-side system weight. On the other hand, the flexure point must be deep enough to clear the draft of the marine traffic.

B. DESIGN IMPLEMENTATION

In order to incorporate the correlations between the experimental and analytical data into a full scale model many variables must be fixed. Appendix H contains detailed calculations concerning the sizing of a large flexure element. The process is summarized here.

a) Cnce a flexure type navigational marker has been chosen to be installed in a particular area, the geographic and environmental parameters must be set, i.e., current and wind speeds to be expected, maximum and minimum water levels, soil type and pile driving conditions, and local marine traffic patterns.

b) The type of navigational package to be supported by the structure will dictate piling size above the flexure element.

c) Based on loading conditions and size of piling to be used, the total moment is calculated using Appendices A and B.

d) Using Equation 17 [Ref. 2, P. 269]

$$\sigma = \frac{MC}{I}$$

apply the critical values of σ obtained from Appendix G, which correspond to certain critical levels of deflection, and knowing approximately what outside diameters are commercially available, solve Equation 17 for the critical inside diameter d. In order to maintain the desired snap-through action, the D to d ratio of the larger scale element should approach those of the experimental model.

Because of the addition of the flexure element in the piling system, the traditional driving sequence must be altered to accommodate the piling modification. Although many methods to accomplish the task exist, Figure 23 presents one method if utilized, after the initial driving sequence, if the marker needs to be changed, repaired, or removed no further use of a pile driver and its associated support equipment are required. First, an 18 inch steel pipe, acting as the male couple, is driven to the desired depth in the soil. A guide line can be attached to this fitting to help position the female coupling. The female coupling, with the flexure element and support piling attached, is lowered and mounted on its male counterpart using ship's handling equipment. Once the flexure element and support piling are in place, the navigational package is installed. As indicated, if the structure is damaged or needs replacement for any reason, the flexure element and support piling need only be pulled off the male coupling, repaired or replaced, then lowered back in its position.

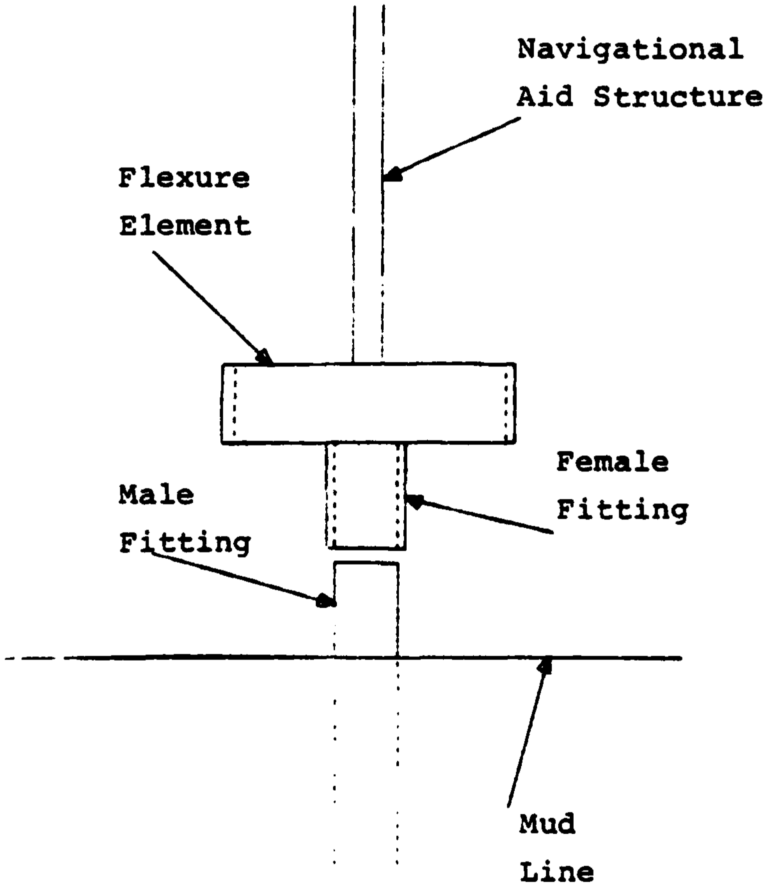


Figure 23. Installation Schematic

C. COST DIFFERENTIAL

Because of the addition of a large flexure element and associated attachment flanges, the material and in-house fabrication cost will be higher than the present system costs. It should be expected that initial installation will require more on-site time to position the male coupling and set the flexure element and navigational package in place. It is anticipated though, that the increased survivability will, when compared to the standard system, make the addition of the flexure element a cost effective modification. Figure 24 compares initial costs and life cycle costs through one collision of the standard system to the flexible system.

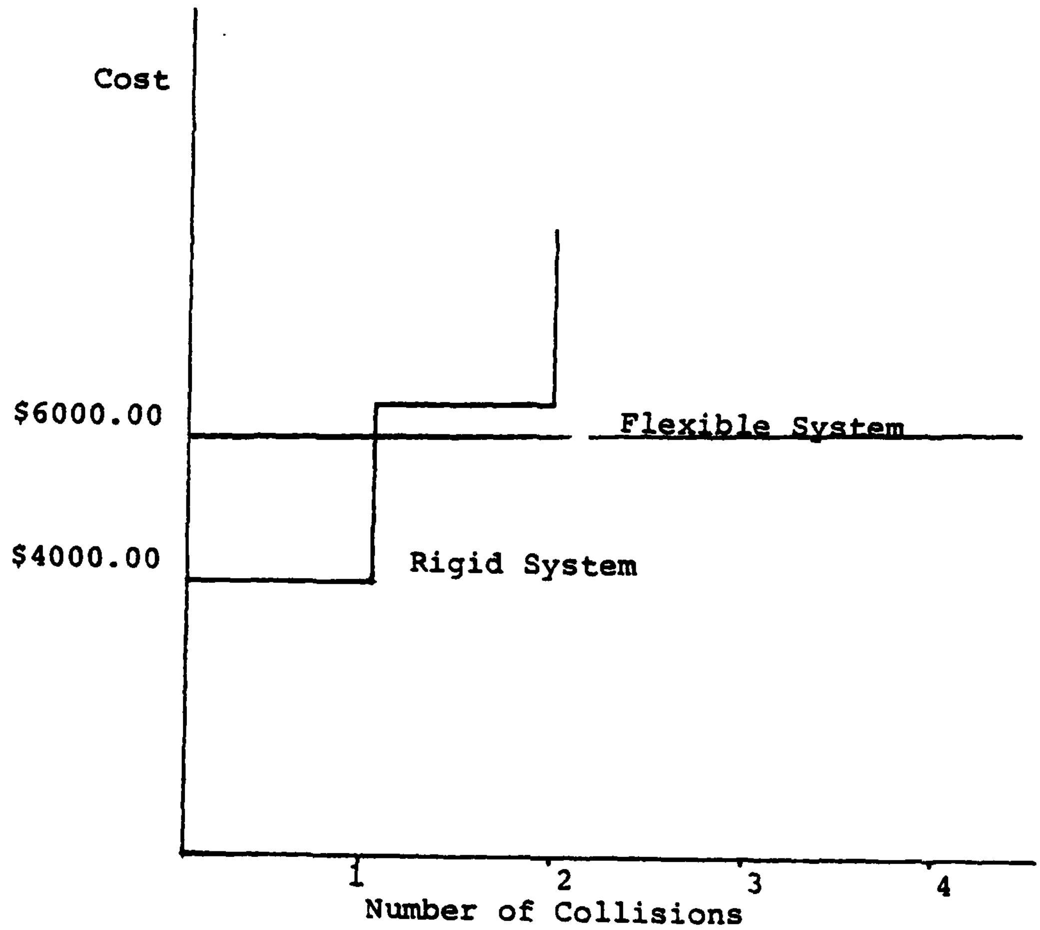


Figure 24. Cost Comparison

VII. CONCLUSIONS

In exploring the feasibility of the CoTo fixed navigational system an experimental model test program was used in an attempt to validate the results of a computer generated model under simulated environmental loadings. The results were very encouraging. It was found that good correlation between experimental model and computer model was achieved from 0 through 10-15 degrees of deflection. Beyond this range, for reasons enumerated within this paper, correlation was poor. It was determined that the results of the computer analysis could be used to predict deflections of the full scale model under the influence of the environmental loads.

Model testing has identified the D/d ratios coupled with the proper L/D ratio which allows for the desired "snap through" behavior. Angles of rotation at which the "snap through" occurs were also discovered through the experimental model tests. Computer analysis was of little value beyond the 15 degrees rotation because of the large divergence of the data and therefore will not be used to determine the "snap through" phenomenon when the element is scaled larger.

A. AREAS FOR FURTHER STUDY

As this work has dealt only with the "static" effect of the calculated environmental loads, no insight was gained into the dynamic impact loading of this flexible structure. It is recommended that a full scale model be built and a series of impact tests be developed and implemented to determine the impact reaction of the flexure system.

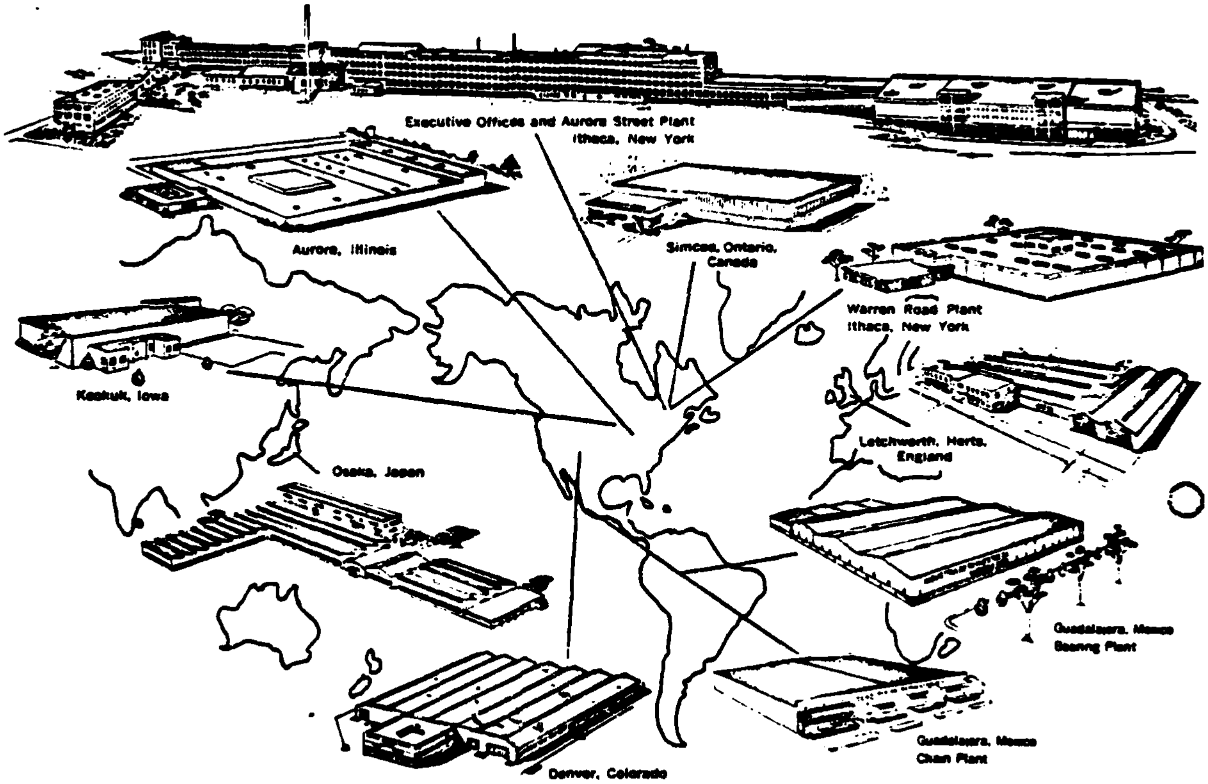
As indicated in this study, as the "snap through" occurs and the local buckling, generated by the collapse of the section of rubber, begins, new dimensions are being created for the changing cross section. When this process is complete, the resulting stresses and strains in this section are very hard to accurately calculate. In turn, the calculation of the righting moment based on the newly formed cross section and resulting moment of inertia becomes very error proned. It is therefore recommended that full scale tests be conducted in conjunction with the impacting test to determine the systems reaction to the complete heel over of the marker's structure.

Any modification of the traditional pile driving sequence creates problems that cannot always be foreseen at the system analysis level. It would best serve the implementation of this system to allow the alternate pile driving scheme to be reviewed by the crews of the tenders with experience in handling such cumbersome tasks.

APPENDIX A

COMMERCIAL LITERATURE

MORSE® Chain,
Division of Borg-Warner Corporation
World-Wide Manufacturing Facilities



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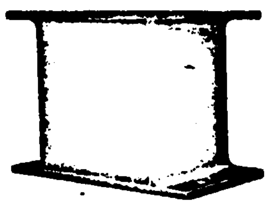
Fendering Design	pages	3 thru 8
Fendering Selection	pages	9 thru 12
Shear Fenders	pages	13 thru 24
Buckling Column Fenders	pages	25 thru 34
Extruded Fenders	pages	35 thru 44
Bumpers	pages	45 thru 47

INTRODUCTION

Rubber has several properties which makes it an ideal material for use in dock fendering systems. It is an elastic material which will undergo a deformation under load, will absorb some of the energy of impact and will return to its original shape when the force is removed. Rubber fenders, for all practical purposes, are considered to be maintenance free. Their large bulk combined with modern compounding techniques make the fenders almost impervious to the effects of weather, sunlight, ozone, and salt water. The large variety in types of fenders available today and the many different ways they can be installed gives the designer a great deal of freedom in designing a fendering system.

Rubber is a member of a class of materials described as high molecular weight polymers; other members of this class being wood, cellulose, plastics, and resins. The distinguishing characteristic of rubber is that the molecular chains are more flexible and become elastic when cross-linked through the vulcanization process. The greater the number of crosslinks in the network, the greater will be the resistance to deformation when a force is applied. Reinforcing fillers such as carbon black when added to the rubber will further increase the resistance to deformation.



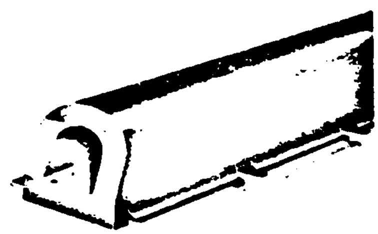
Hardness measurements are one of the basic methods used to characterize rubbers. It is essentially a measurement of the degree of elastic deformation produced by a specially shaped indentor under a specified load and is, therefore, related to the Young's modulus of the rubber. Tensile stress-strain properties are another method used to characterize rubbers and are used frequently for specifications and quality control during manufacture. The load-deflection curves for rubber in tension and compression are approximately linear for strains of the order of a few percent and values for Young's modulus E_0 can be obtained from these linear regions.

Although an elastic material, rubber is considered to be almost incompressible with a modulus of bulk compression similar to that of water. In order to act as a soft spring in compression, the rubber fenders must be given the opportunity to bulge laterally. Fender shape must accommodate the movement, resulting in different physical configurations to satisfy the requirements of a variety of applications.

ENVIRONMENTAL EFFECTS

As a fender, rubber will be exposed to the effects of sunlight, oxygen, ozone, temperature variations and salt water and, in some cases, to the additional effects of industrial chemicals.

Black rubber fenders are effectively protected from deterioration by sunlight because the carbon black fillers block out the ultraviolet radiation. Light colored fenders are more susceptible to oxidation that is initiated by ultraviolet radiation. Elevated temperatures will accelerate the degradative attack by both oxygen and ozone. There are some factors which will minimize these effects.



First, protective agents are incorporated in the rubber formulations. Second, the fenders are not subjected to an environment of elevated temperatures. Third, oxidative attack can take place only on the surface of the rubber and, because of the large cross-section of rubber in these fenders, the overall effect is negligible.

Ozone attack of rubber is becoming a matter of increasing concern as concentrations of ozone in the atmosphere appear to be increasing each year. It requires only a concentration of a few parts per hundred million of ozone to crack unprotected rubber in a matter of weeks. However, there are some characteristics of ozone attack which again make its effect on fenders negligible. A certain minimum tensile strain is required before ozone cracks will appear. This minimum strain is about 10 to 20%, the cracks forming perpendicular to the direction of strain. In compression, the rate of ozone attack is slower by the order of a hundred times than when in tension. Again, ozone attack is a surface problem and will have drastic effects on thin cross-sections and almost no effect on large cross-sections.

Some types of rubber such as "EPDM" and "Butyl" are inherently resistant to attack by ozone. Other rubbers commonly used in fenders such as "Natural" rubber and "SBR" will require the use of protective materials in the formulation in addition to the careful design of the part to minimize areas that will be subjected to tensile strain.

Fresh or salt water will not have any detrimental effect on the rubber even if the fenders are to be immersed for long periods of time. Hydrocarbon liquids such as oils, solvents, and fuels will seriously degrade rubber fenders. However, an occasional spill will not be harmful because the amount of liquid absorbed is proportional to the square root of the time the liquid is in contact with the rubber.

In terms of resistance to chemicals, rubber is considered to be inert in most instances. It is resistant to salts and alkalies and most acids, the exceptions being concentrated sulfuric, nitric and chromic acids.

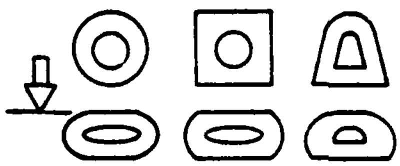
ELASTOMER PROPERTIES CHART

PHYSICAL PROPERTIES		NR NATURAL RUBBER	SBR STYRENE BUTADIENE	CR NEOPRENE	EPDM ETHYLENE PROPYLENE DIMONOMER	IIR BUTYL	NBR NITRILE BUTADIENE
POLYMER SPEC. GR.		.93	.93	1.23	.86	.92	1.00
DUROMETER RANGE		30-100	30-100	40-95	30-90	30-100	30-100
TENSILE STRENGHT (PSI)		4000+	3000	3000	2500	2000+	3000
ELONGATION (%)		TO 700	500	TO 800	TO 500	600	TO 700
TEAR RESISTANCE		EXCELLENT	GOOD	GOOD	FAIR	GOOD	GOOD
WEATHER RESISTANCE		FAIR	FAIR	GOOD	EXCELLENT	EXCELLENT	FAIR
OZONE RESISTANCE		POOR	POOR	GOOD	EXCELLENT	EXCELLENT	POOR
WATER RESISTANCE		EXCELLENT	EXCELLENT	FAIR	EXCELLENT	EXCELLENT	GOOD
OIL & GASOLINE RESISTANCE		POOR	POOR	GOOD	POOR	POOR	EXCELLENT
SOLVENT RESISTANCE	ALIPHATIC HYDROCARBON	POOR	POOR	GOOD	POOR	POOR	EXCELLENT
	AROMATIC HYDROCARBON	POOR	POOR	POOR	FAIR	POOR	GOOD
BRITTLE POINT (°F)		-80	-60	-40	-90	-80	-65
STIFFENING POINT (°F AVG.)		-40	-35	-10	-35	-25	-10
COMPRESSION SET		GOOD	GOOD	FAIR	FAIR	FAIR	GOOD
TEMPERATURE RESISTANCE	212°F	FAIR	GOOD	GOOD	EXCELLENT	EXCELLENT	EXCELLENT
	350°F	POOR	POOR	POOR	FAIR	FAIR	FAIR
	450°F	POOR	POOR	POOR	POOR	POOR	POOR
GAS IMPERMEABILITY		GOOD	FAIR	GOOD	GOOD	EXCELLENT	GOOD
ABRASION RESISTANCE		EXCELLENT	EXCELLENT	GOOD	GOOD	EXCELLENT	GOOD
FLEX RESISTANCE		EXCELLENT	GOOD	GOOD	GOOD	GOOD	FAIR

DESIGN

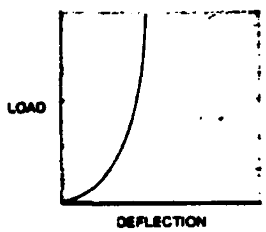
Morse manufacturers three basic types of fenders; extrusions, buckling fenders and shear fenders.

Extruded fenders will normally have cross-sections that are either cylindrical, rectangular or triangular; each having a hollow bore to increase the deflection for a given load.

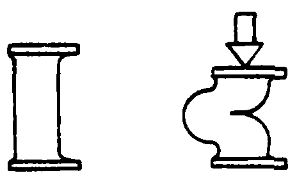


When a curved surface of a rubber fender is compressed against a rigid plane, the stiffness generally increases as the area of contact increases during deformation. The load-deflection characteristics then are non-linear. For a hollow section there is a sharp increase in stiffness as soon as the amount of deflection equals the diameter of the bore.

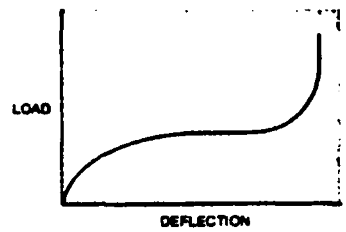
Extruded fenders work well in applications where the loads to be absorbed are not so large that the required deflection exceeds the fender's capability. They also are ideal for rub rails on line hulls, docks and concrete walls to prevent damage by scraping. A typical load-deflection curve for a cylindrical extrusion is shown below.



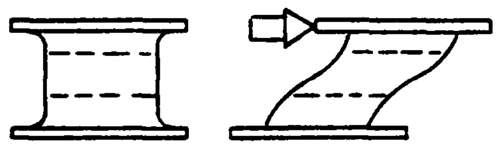
The "buckling" fender has several advantages over the extruded type of fendering. It is based on a buckling column principal and is basically a molded column of rubber bonded to steel end plates.



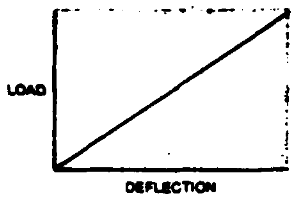
The characteristics of the buckling fender are that it requires a relatively large load to initiate any deflection and only a small additional load to collapse the fender to full deflection. After the fender is collapsed, any further deflection will require a sharp increase in the load. The fenders are designed to buckle in a predetermined direction. The buckling fender then can provide a so-called "soft" fendering system for large loads by absorbing large amounts of energy at a given deflection compared to fenders used in compression. Buckling fenders must be restrained from undergoing lateral movement in operation as it will reduce their effectiveness. Below is a typical curve for a buckling fender.



Shear fenders consist of rectangular blocks of rubber bonded to steel end plates and are designed to react to loads in shear.



In addition to providing a "soft" fendering system such as the buckling fender, shear fenders have some definite advantages over buckling fenders. The deflection of a shear fender is not limited to one direction; therefore, the designer need not be concerned with restricting those forces that are not normal to the dock. The shear fender will accommodate loads not normal to the dock and can even function when in torsion or compression. If a deflection greater than the design limits of the individual shear fender is required, it can be obtained by bolting two or more fenders together. The typical load-deflection curve for a shear fender is linear which illustrates that a shear fender does not exhibit a sudden resistance to additional load as happens with extruded fenders and buckling columns (compare the representative deflection curves).



CALCULATIONS

When a fender system is to be designed, it will usually fall into one of three general categories:

1. It can be an existing dock that is to be improved and upgraded to more modern standards.
2. It could be a new or existing facility that is strong enough that horizontal docking forces on it are secondary to vessel hull reaction force limits.
3. It could be a new facility, open dock or dolphin, built on jacketed piles and requiring the most efficient and economical fendering system possible to provide docking for large vessels.

Although the formulas used are the same in each case, the values assigned and the unknowns calculated from these assignments will require careful evaluation to determine priorities in each individual case.

To insure that the key factors are taken into account, a table listing pertinent items is included. It should be filled out as completely and accurately as possible as the first step in design.

ITEM	UNITS	VALUE	OTHER UNITS	NOMOGRAPH
VESSEL DISPLACEMENT	LONG TN.		KIPS (LG. TNS.x2.24)	4
VESSEL LENGTH	FEET		METERS (FT. x .305)	2
VESSEL BEAM	FEET		METERS (FT. x .305)	1
VESSEL DRAFT	FEET		METERS (FT. x .305)	1 & 2
ALLOWABLE HULL REACTION	KIPS		MET. TN (KIPS x .453)	
ALLOWABLE DOCK REACTION	KIPS		MET. TN. (KIPS x .453)	
APPROACH VELOCITY-MAX. V_F	FT / SEC		MET/SEC (FT/SEC x .305)	3
APPROACH ANGLE α	DEGREES		NONE	3
COEFFICIENT OF ECCENTRICITY	NONE	USUALLY 0.5	BERTHING COEFF.	

FENDER SELECTION CHART

ITEM						
1	MAX. REACTION (FROM TABLE 1) LOWEST REACTION-HULL OR DOCK	KIPS				
2	CALCULATED ENERGY "E" (FROM NOMOGRAPH № 4)	FT KIPS				
3	DESIGN MAX. $\frac{R}{E} = \frac{\text{ITEM 1}}{\text{ITEM 2}}$	KIPS/FT KIP				
4	PRELIMINARY FENDER SELECTION					
5	R/E OF FENDER (FROM FENDER APP. CURVE AT DESIGN DEFLECTION)					
6	LOAD "R" OF FENDER AT DESIGN DEF. (FROM APP. CURVE) KIPS					
7	ENERGY "E" OF FENDER AT DESIGN DEF. (FROM APP. CURVE) FT KIPS					
8	QUANTITY OF FENDERS REQ'D. TO MEET THE LOAD = ITEM 1 / ITEM 6					
9	QUANTITY OF FENDERS REQ'D. TO MEET ENERGY ABSORPTION = ITEM 2 / ITEM 7					

The basic energy formula as stated by Newton is:

$$E = \frac{1}{2} MV^2$$

E = Energy of a body (vessel) in motion
M = Mass = Weight/Gravity Constant
V = Velocity of the body in motion

This formula has been modified to include the following factors in dock design:

A. Vessel displacement calculated and converted to units of mass (M)
B. Hydrodynamic effect of water moving with the vessel and pushing it (Two methods outlined)
C. Velocity component at 90° to the dock facility
D. Coefficient of eccentricity or berthing coefficient
E. Coefficient of facility construction

The working formula therefore becomes:

$$E = \frac{1}{2} \left(\frac{W_T}{g}\right)(V_n)^2 (C_E)(C_C)$$

$$W_T = W_V + W_C + W_H$$

Where E = Energy to be absorbed by the fendering
W_T = Total effective displacement (converted to Kips)
W_V = Weight of the light vessel (converted to Kips)
W_C = Vessels cargo weight DWT (converted to Kips)
W_H = Hydrodynamic effect
g = Gravitational constant
V_n = Velocity of vessel normal to the dock
C_E = Coefficient of eccentricity or berthing coefficient
C_C = Coefficient of facility construction

Note: 1 Kip = 1000 pounds

Determine the total mass M: the mass of the empty vessel plus the mass of the cargo plus the hydrodynamic mass.

$$M = \frac{W_T}{g}$$

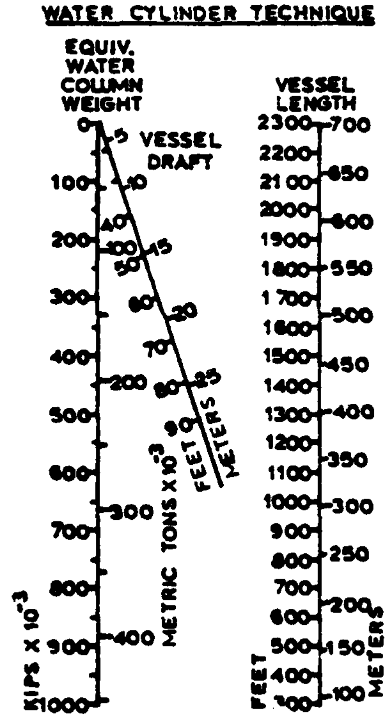
W_T is the total effective displacement converted to Kips. It can be determined by either of two methods:

1. $W_T = W_V + W_C + W_H$

W_H, the hydrodynamic effect, describes the displacement of water moving with the vessel. A method for approximating the hydrodynamic effect is to assume a cylinder of water moving with the vessel that is equal in length to the vessel and of a diameter equal to the vessel's draft. Nomograph #1 will give a ready reference solution to the formula:

$$W_H = \frac{\pi}{4} D^2 L P$$

Where P is the density of water



No. 1

W_V is the weight of the vessel light or empty. The maximum value for the class of vessel to be docked at the facility should be used. Usually expressed in long tons, or metric tons, this value should be added to W_C which is the *DWT* (Dead weight tons) of cargo the vessel is designed to carry. Since all units in this guide refer to Kips or metric tons, long tons must be converted to Kips by multiplying by 2.24

An alternate method for determining W_T, the total effective displacement, is:

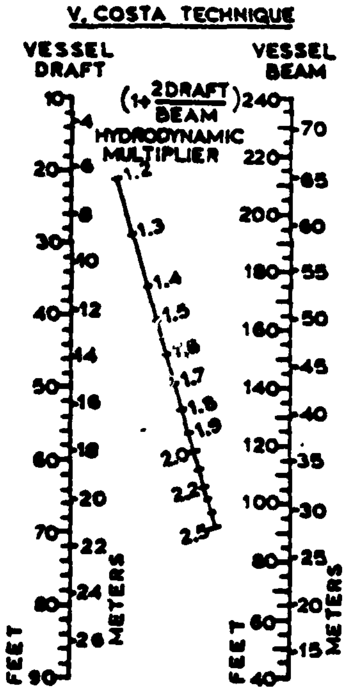
$$2.\quad W_T = \left(1 + \frac{2D}{B}\right)\ (W_V + W_C)$$

Where $\left(1 + \frac{2D}{B}\right)$ is the hydrodynamic coefficient

and

D = Draft of the vessel
B = Beam of the vessel

Since D and B have the same units, the coefficient is dimensionless and can be used with any units of weight. Use of Nomograph #2 is convenient for determination of this coefficient and has D and B in both feet and meters.



No. 2

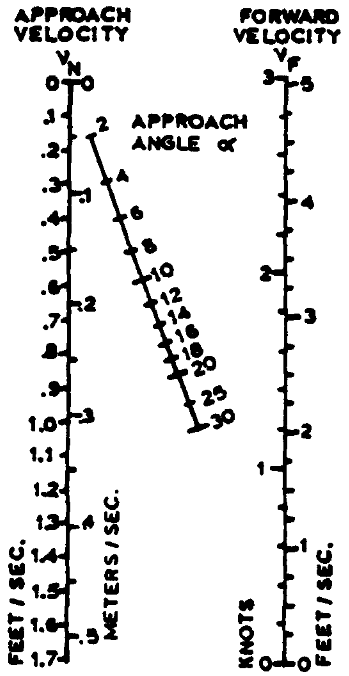
A third school of thought states that WH need not be considered with open dock construction. Alonzo De F. Quinn in his book *Design and Construction of Ports and Marine Structures* (2nd ed. Page 384) states "When the vessel is berthing against an open pier or dolphins on piles where there is little obstruction to the water moving with the ship — additional weight may be disregarded."

Mass is determined by dividing the total equivalent weight WT by the gravitational constant

g = 32.2 ft. per sec.^{2} for English units

g = 9.814 meters per sec.^{2} for metric units

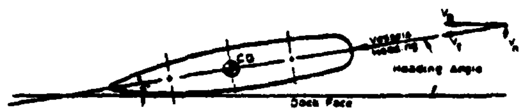
V_n: The velocity normal, or at a right angle to the dock face or breasting line in the case of dolphins, is the only velocity component used in calculating the berthing energy load. V_n is further defined and illustrated in the sketch below. Even though the vessel may dock under its own power or be tug assisted, V_n is always the vector 90° to the dock. Nomograph No. 3 gives values of V_n in both feet per second and meters per second for approach angles up to 30°.



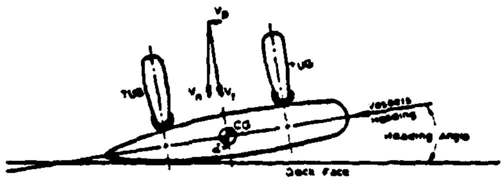
No. 3

$V_n = V_t \sin \alpha$

Where: V_t = Velocity of the vessel relative to the dock
α = Angle between V_t and the dock face (90° or less) called the approach angle



When a vessel docks under it's own power, V_t = Vessel Heading and α is approximately equal to the heading angle



When a vessel is tug assisted in docking, V_t = 90° to the Vessel Heading and α is approximately the compliment of the heading angle

C_E: The coefficient of eccentricity, or berthing coefficient, as it is sometimes referred to, takes into account that the vessel does not always berth with its longitudinal axis parallel to the dock face. In moving to this position from some angle, the vessel rotates about its center of gravity (C.G.). This rotation uses up some of the Kinetic energy that would otherwise be taken by the dock fendering if the vessel contacted parallel to the dock and at the midpoint of the vessel. Therefore, if a vessel makes initial contact with a dock at something other than parallel closing, not all of the energy needs to be absorbed by the fenders. The amount of attenuation is relative to the geometry of the vessel and the point at which it makes initial contact with the dock. Mathematically expressed as:

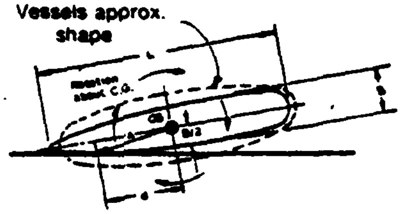
$$C_E = \frac{K^2}{K^2 + A^2}$$

Where K = Radius of gyration of the vessel
A = Distance between the vessel's C.G. and the point of impact with the dock

If a vessel can be assumed to be an ellipse, then

$$K = \frac{L}{4} \text{ or } 0.25L$$

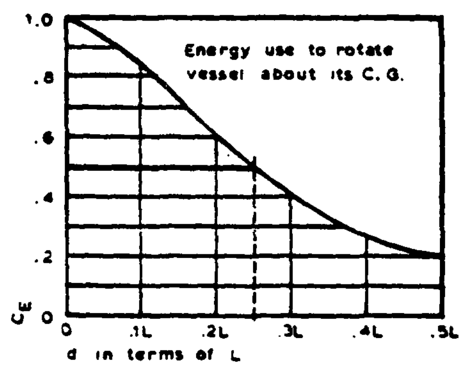
Ellipse ($K = L/4$)



To calculate A, the point of contact with the dock must be determined and the beam of the vessel must be known. Then from the Pythagorean theorem:

$$A^2 = (\frac{B}{2})^2 + d^2 \quad \text{(see sketch above)}$$

From many calculations on many vessels, it has been determined that C_E can be related to the point of contact with the dock and relates as follows:



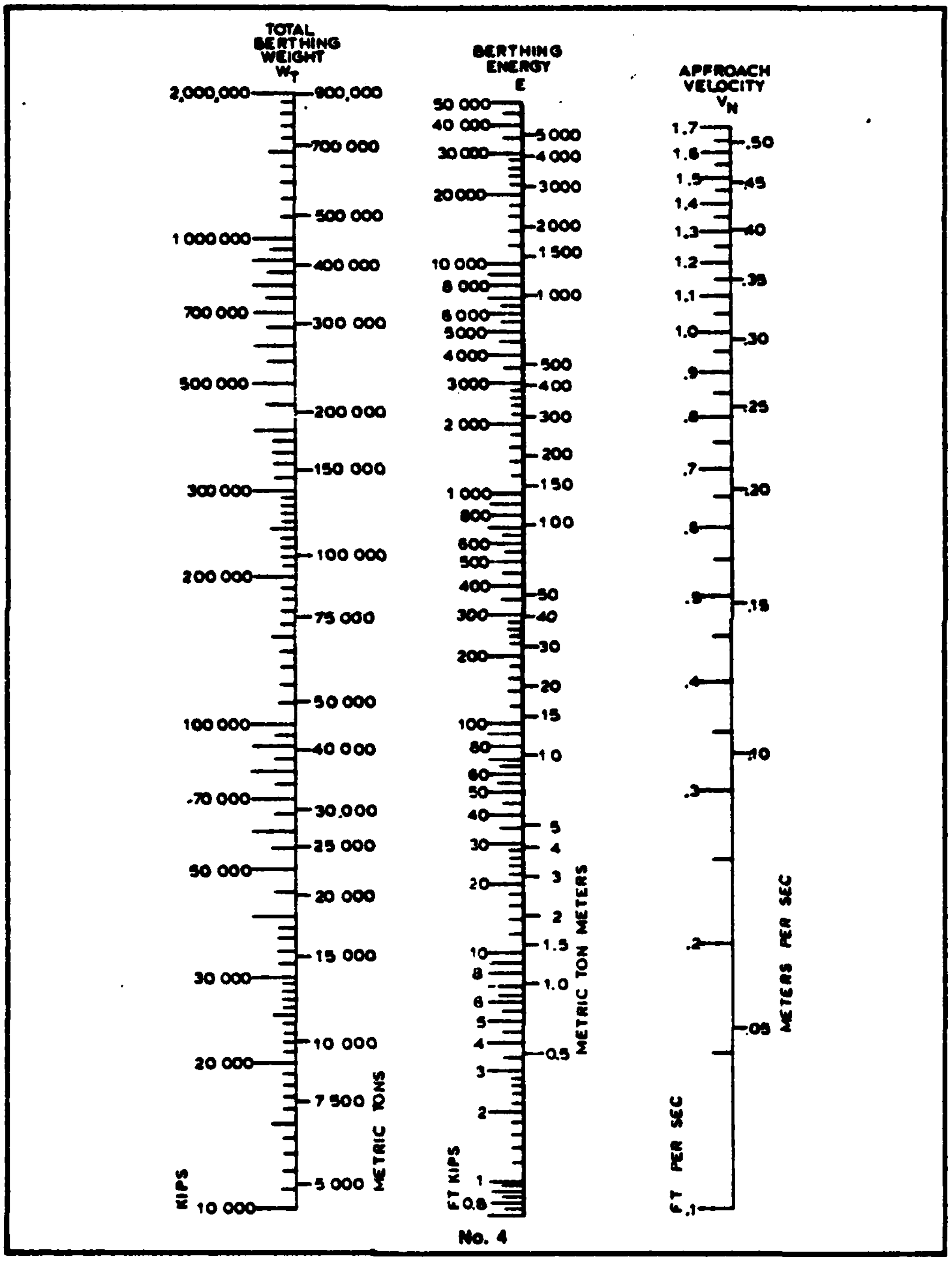
From observations of many dockings, C_E has been found to average 0.5 and unless specific information is known about docking conditions and vessel configuration, this value is generally accepted.

C_C: The coefficient of construction adjusts the value of energy to be absorbed based on dock construction. Some typical values for C_C are listed below:

Jacket pile (open construction) - 1.0

Continuous wall or sheet pile - 0.8

This coefficient has not been included in the design of Nomograph 4 (shown on page 8) for determination of berthing energy, therefore, the designer should choose a value using the above examples as guidelines and insert it into his final calculations.


TOTAL BERTHING WEIGHT W_T
BERTHING ENERGY E
APPROACH VELOCITY V_N
KIPS
METRIC TONS
FT KIPS
METRIC TON METERS
FT PER SEC
METERS PER SEC
No. 4

FENDER SELECTION

STEP 1

List all pertinent information per Table I (shown on page 4)

ITEM	UNITS	VALUE	OTHER UNITS	NOMOGRAPH
VESSEL DISPLACEMENT	LONG TN.	150,000 L.T.	KIPS (LG. TNS x 2.24)	4
VESSEL LENGTH	FEET	1000 FT.	METERS (FT. x .305)	2
VESSEL BEAM	FEET	150 FT.	METERS (FT. x .305)	1
VESSEL DRAFT	FEET	56 FT.	METERS (FT. x .305)	1 & 2
ALLOWABLE HULL REACTION	KIPS	1000 Kips	MET. TN (KIPS x .453)	
ALLOWABLE DOCK REACTION	KIPS	15,000 Kips	MET. TN. (KIPS x .453)	
APPROACH VELOCITY-MAX. V_F	FT/SEC	2.5 FT./sec.	MET/SEC (FT/SEC x .305)	3
APPROACH ANGLE α	DEGREES	10°	NONE	3
COEFFICIENT OF ECCENTRICITY	NONE	USUALLY 0.5	BERTHING COEFF.	

STEP 2

Determine the total berthing weight. In this example, the water cylinder technique will be used to determine the additional berthing weight caused by the hydrodynamic effect. Thus:

$$W_T = W_V + W_C + \frac{\pi}{4} D^2 L\ P$$

or

W_T = Displacement plus water column

Substituting from Table I and converting to Kips gives:

$$W_T = 150{,}000\ lg.\ tns \times 2.24\ \frac{Kips}{lg.\ tn} + 154{,}000\ Kips^* = 490{,}000\ Kips$$

*This value from Nomograph 2 (shown on page 6), using D and L from Table I above. Note: All three methods of obtaining WT are compared at the end of this sample calculation.

STEP 3

Determine the normal berthing velocity (V_n)

From Table 1 V_f = 2.5 ft./sec.

From Nomograph 3 (shown on page 6), or using the formula $V_n = V_f$ Sin

V_n = .43 ft./sec. pick

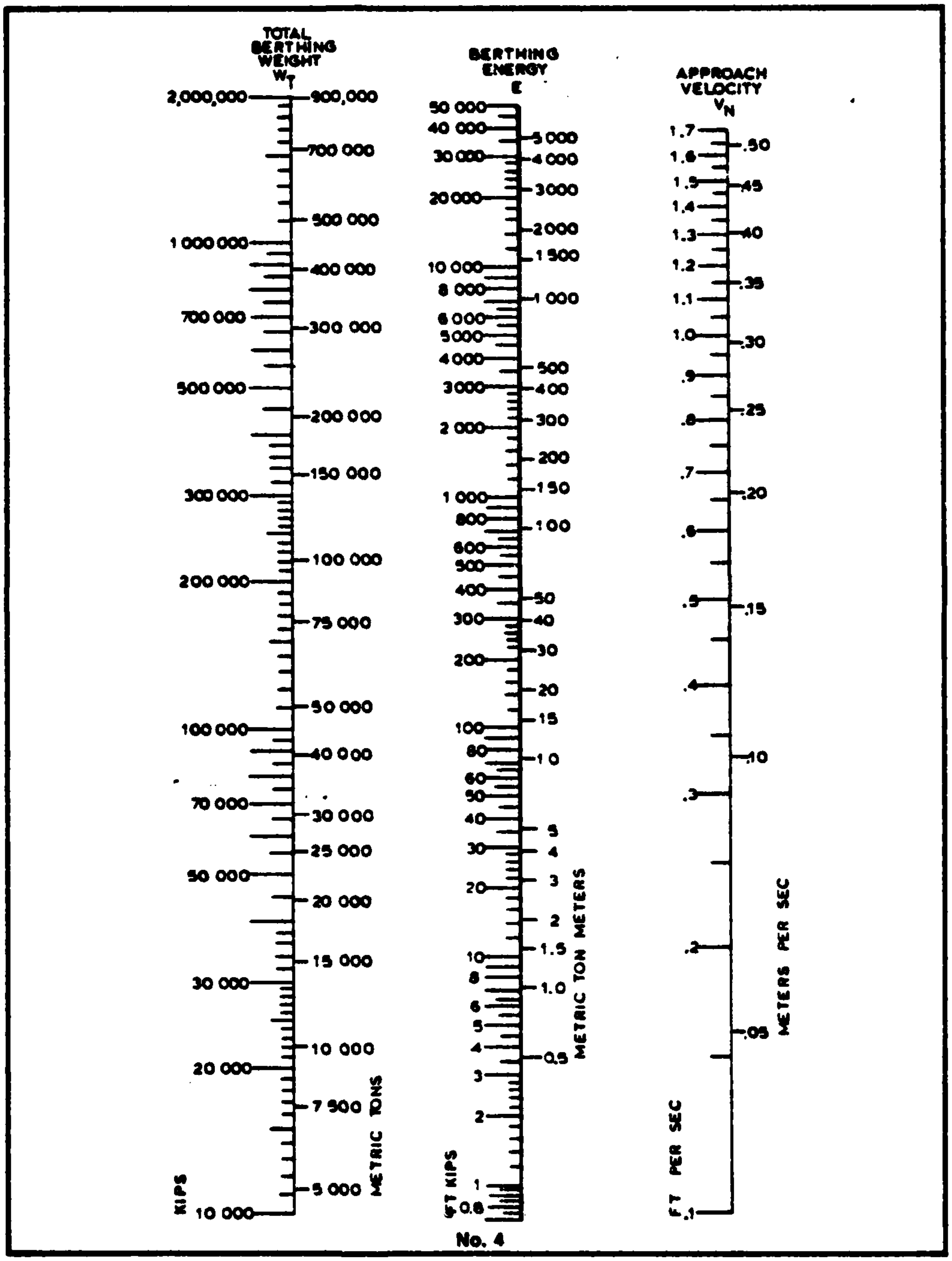
STEP 4

Determine the berthing energy:

$$E = \frac{1}{2}\left(\frac{W_T}{g}\right)(V_n)^2\ (C_E)(C_C)$$

To determine the total berthing energy, values must be established for C_E and C_C. For simplicity, the value of C_E will be assumed to be 0.5, a generally accepted average value unless specific design states otherwise. It is this value that was used in the design and layout of Nomograph 4 (shown on page 8). C_C will be taken as 1.0, assuming open jacketed pile construction. This value was also used to design and layout Nomograph 4. If other than these values are used, appropriate mathematical adjustments must be made in the values obtained using Nomograph 4, or the entire equation could be calculated. Therefore, using Nomograph 4, if V_n = 0.43 and W_T = 490,000 Kips then E can be determined from Nomograph 4 to equal:

E = 703 Ft. Kips


TOTAL BERTHING WEIGHT W_T
BERTHING ENERGY E
APPROACH VELOCITY V_N
KIPS
METRIC TONS
FT KIPS
METRIC TON METERS
FT PER SEC
METERS PER SEC
No. 4

STEP 5

Referring to the example in Table I (shown on page 4), determine the maximum R/E acceptable. From Table I it is seen that the limiting factor is the allowable hull reaction. That value is 1000 Kips. Therefore,

R = 1000 Kips

From the previous step using Nomograph 4: (shown on page 10)

E = 703 Kips

The ratio then is:

$$\frac{R}{E} = \frac{1000 \text{ Kips}}{703 \text{ Kips}} = 1.42, \text{ maximum allowable value.}$$

STEP 6

After studying the R/E curves for Morse fenders, list all fender selections that meet the R/E specification of 1.42 or less at the desired deflection. For this example, the rated deflection will be assumed to be the design deflection; however, other systems may be designed to have specific deflections other than the rated deflection.

Looking at the application curves for R/E, the following fenders are found to have suitable values:

12" Shear Fender
14" Shear Fender
16" Shear Fender
33" Buckling Column
48" Buckling Column

STEP 7

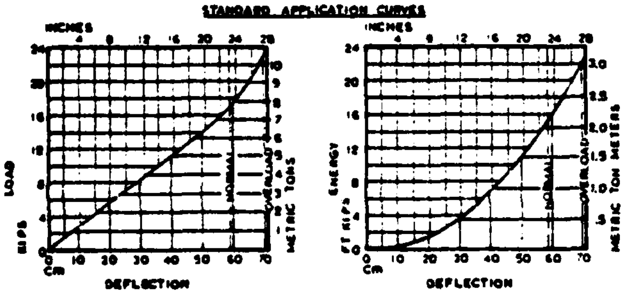
Fill in the fender selection chart.

FENDER SELECTION CHART

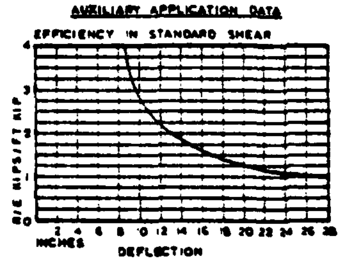
ITEM						
1	MAX. REACTION (FROM TABLE 1) LOWEST REACTION-HULL OR DOCK	1000 KIPS				
2	CALCULATED ENERGY "E" (FROM NOMOGRAPH № 4)	703 FT KIPS				
3	DESIGN MAX. $\frac{R}{E} = \frac{\text{ITEM 1}}{\text{ITEM 2}}$	1.42 KIPS/FT KIP				
4	PRELIMINARY FENDER SELECTION	12" S.F.	14" S.F.	16" S.F.	33" B.C.	48" B.C.
5	R/E OF FENDER (FROM FENDER APP. CURVE AT DESIGN DEFLECTION)	1.25	1.1	.98	1.00	.63
6	LOAD "R" OF FENDER AT DESIGN DEF. (FROM APP. CURVE) KIPS	12.5 Kips	17 Kips	21.5 Kips	21 Kips	38 Kips
7	ENERGY "E" OF FENDER AT DESIGN DEF. (FROM APP. CURVE) FT KIPS	10 ft. Kp.	15 ft. Kp.	22 ft. kp.	21 ft. kp.	59 ft. Kp.
8	QUANTITY OF FENDERS REQ'D. TO MEET THE LOAD = ITEM 1 / ITEM 6	80	58.8	46.5	47.6	26.3
9	QUANTITY OF FENDERS REQ'D. TO MEET ENERGY ABSORPTION = ITEM 2 / ITEM 7	70.3	46.9	32.0	33.5	11.9

This chart allows for up to five possible fender selections. By filling in the values from Table I, calculations, nomographs and application curves as noted, a study can be made to determine the best fender for a specific need. (See sample data taken from the 14" shear fender application curves. Shown below.)

STANDARD APPLICATION CURVES



AUXILIARY APPLICATION DATA



After the fender selection chart has been filled out, review and consider such questions as:

A. What configuration of fenders suits the design?
B. What safety factor should be used?
C. How will fender selection affect maintenance?
D. Does the design require omnidirectional capability?

Note: See longitudinal force section (shown on this page).

Although 27 units of 48" buckling column would meet the load and energy requirements, 47 units of 16" shear fender would divide the load on the structure into much smaller segments and would induce significantly lower shock as a reaction to high load levels. This illustration considers only part of the variables normally encountered in a design problem. Since a complete analysis of all variables is beyond the scope of this manual, the designer is left to choose the Morse fender best suited to his design requirements.

ALTERNATE METHODS OF DETERMINING TOTAL BERTHING WEIGHT (W_T)

A. $W_T = W_V + W_C$ (No hydrodynamic effect considered)

W_T = Displacement = 150,000 lg. tn.

$= 150{,}000 \text{ lg. tn.} \dfrac{(2.24 \text{ Kips})}{\text{lg. tn.}} = 336{,}000 \text{ Kips}$

B. $W_T = (W_V + W_C)\left(1 + \dfrac{2D}{B}\right)$ (Vasco Costa Technique)

$W_T = \text{Displacement}\left(1 + \dfrac{2 \times 56}{150}\right)$

$= 150{,}000 \text{ lg. tn. } (1.75) \dfrac{(2.24 \text{ Kips})}{\text{lg. tn.}}$

= 588,000 Kips

C. $W_T = W_V + W_C + W_H$

$= \text{Displacement} + W_H$

$= 150{,}000(2.24) + \frac{\pi}{4}(56)^2(1000)(62.4) \times \dfrac{1 \text{ Kip}}{1000 \text{ lb.}}$

= 489, 691 Kips

Compare this value with 490,000 Kips obtained from Nomograph 2 (shown on page 6).

Morse does not recommend any one method of calculation of W_T over another.

LONGITUDINAL FORCES ON DOCK FACES

As a vessel slides along a dock face in berthing, it induces longitudinal forces due to friction between the vessel's hull and the dock face. This longitudinal force on the dock can be calculated using the formula:

$$F_L = \mu N$$

Where: F_L = Induced longitudinal force
μ = Coefficient of friction between dock face and vessel hull
N = R minimum

In the sample calculation, if the dock was oak and the vessel was steel,

μ = 0.33 and substitution would yield

$F_L = Rmm$
F_L = .33 (1000 Kips)
F_L = 330 Kips

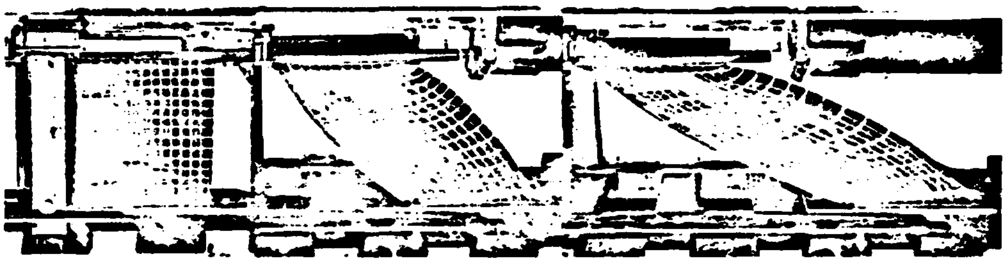
Assuming this to act at a 45° angle, the load (plus a safety factor) must be taken by chains or other restraints if buckling columns are used or by shear fenders directly without restraints.

Assuming selection of 14" shear fenders, the oblique load deflection curve shows:

$\dfrac{330 \text{ Kips}}{59 \text{ Fenders}}$ = 5.59 Kips Load/Fender

This load would deflect the dock face 7.5 inches according to the oblique load deflection curve for 14" shear fenders.

Similar evaluation of all fender selections can be made using the appropriate curves.



THE MORSE SHEAR FENDER

Consider how these special features will solve difficult design problems or allow new freedom of design in dock structures.

OMNIDIRECTIONAL

A Shear Fender can stretch in all four shear directions, plus take large compression and limited tension loads. This feature allows for wale movement away from the dock, into the dock, or tangential to the dock as a berthing vessel slides along. In compression, the fender can be used alone or in tandem, bolted between a wall and wale. Tension and compression loading allow the Shear Fender to support the wale, assisting the pile or chain supports. This is truly a unique feature of Shear Fenders.

BUILDING BLOCK FENDER

No other dock system can be tailored to meet the specific requirements that Morse Shear Fenders provide. Shear Fenders can be mounted in varying density, allowing up stream or windward areas of the facility to be stronger than the other sections. Only one size Shear Fender needs to be used. This has a direct bearing on the economy of construction and also reduces future maintenance cost.

DURABILITY

Each Shear Fender is tested before shipment, see photos, to insure long service life. Most cases of failure are due to on-sight mechanical abuse of the rubber shear block, not end plate separation. The durability of the mechanical and chemical bonded end plates have been proven over years of service by hundreds of fenders.

EASE OF SERVICE

A Shear Fender can be replaced by removing eight bolts. No need to interrupt service, because Shear Fenders are building blocks. Removal of one Shear Fender for replacement does not incapacitate the facility. The remaining Shear Fenders carry the load until the new fender is installed; again, with just eight bolts.

UNIFORM LOAD TRANSFER

Shear Fenders may be placed over the entire face of the dock, from top to bottom, allowing more uniform transfer of berthing loads to the dock structure. This eliminates high load concentrations caused by only a few points of load transfer between the wale and dock structure. An added feature of this type of dispersion of fenders, is the fact that berthing loads are always taken at or near a fender, eliminating overloads due to torque.

The following pages contain dimensional data, mounting recommendations, application data, plotted both in metric and English units, and some typical installation drawings. Should other data be required, contact your nearest Morse Service Center.

SPECIFICATION: SHEAR FENDERS

The Morse Shear Fender shall be an assembly consisting of:

1. A rubber shear block made of ASTM D-2000 *NEOLASTIC* rubber and meeting the following ASTM test values 5AA425 A_{13} B_{13} C_{20} F_{17} K_{11} L_{14}
2. Metal insert plates embedded in and bonded to that block, such plates being completely encased in rubber for corrosion protection.

Design deflection shall be ________ In. or Cm. (See Product Data Curve)

Design Load (Reaction) shall be ________ Kips or Met. Tons (See Product Data Curve)

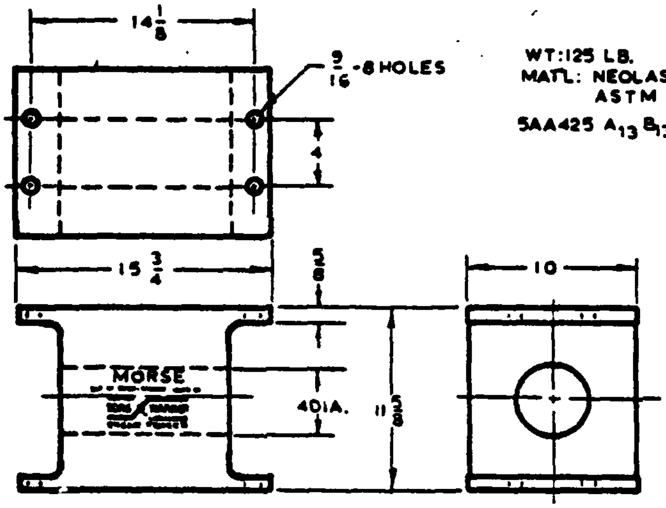
Design Energy Absorption shall be ________ Ft. Kips or Met. Tn. Mets. (See Product Data)

Maximum Overload Expected to be ________ Kips or Met. Tons

Specifications subject to change without notice.

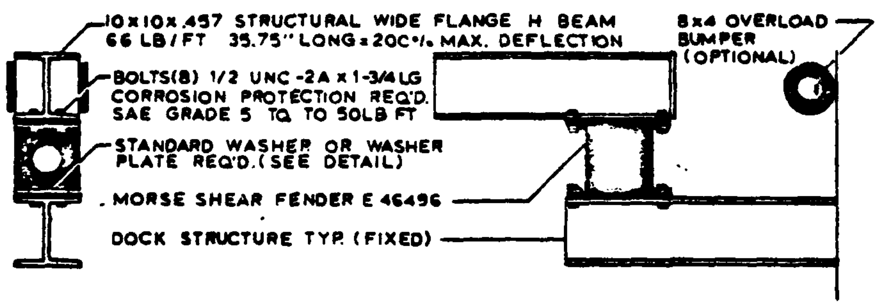
Certified prints provided with quotation on request.

10" SHEAR FENDER • Part No. E46496 U.S. PAT. 3,763,653



WT:125 LB.
MAT'L: NEOLASTIC® RUBBER
ASTM D-2000
5AA425 A_{13} B_{13} C_{20} F_{17} K_{11} L_{14}

MOUNTING RECOMMENDATIONS

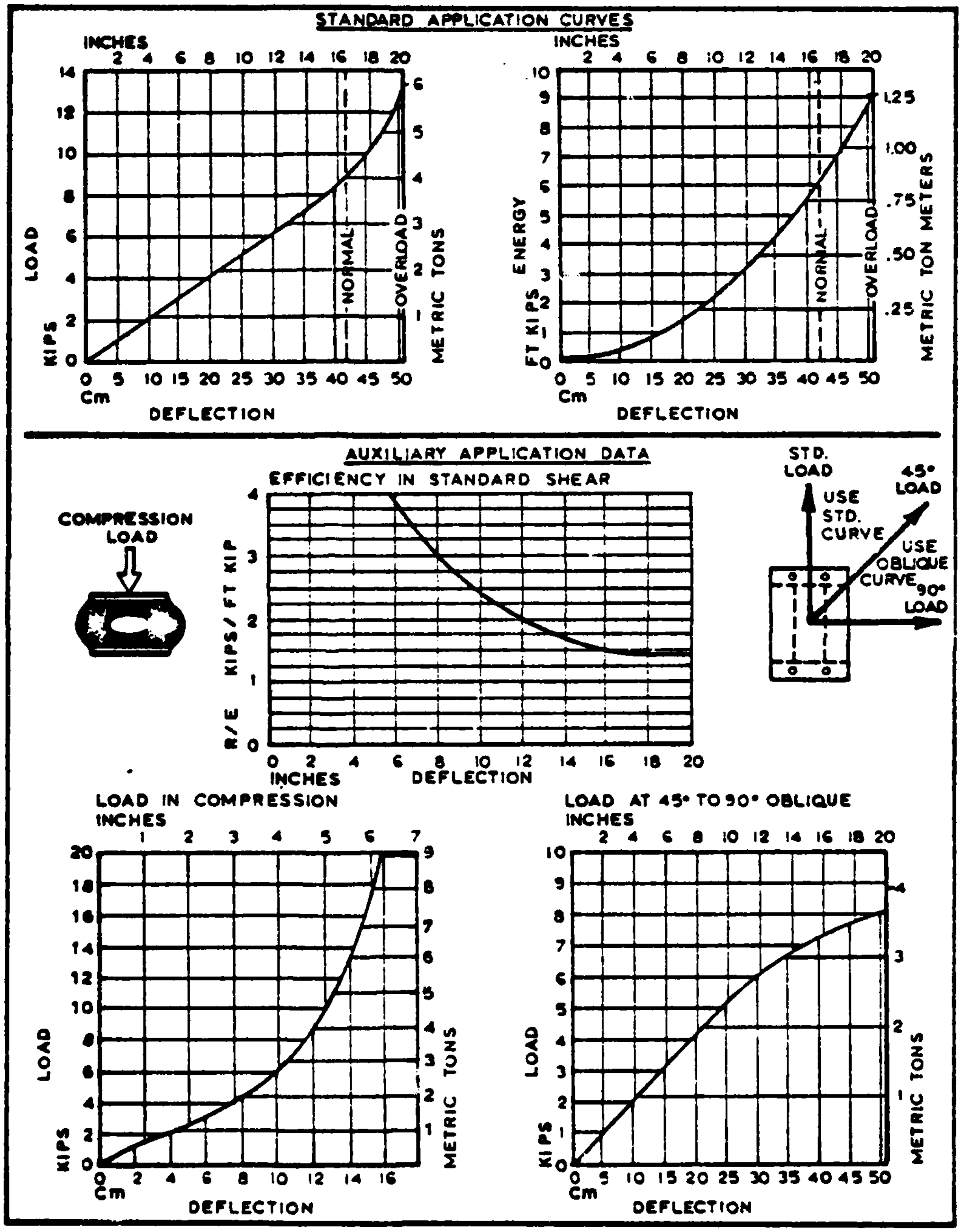


10" SHEAR FENDERS WILL SUPPORT 2 KIPS IN COMPRESSION WITH NO NOTICABLE CHANGE IN THE SHEAR REACTION

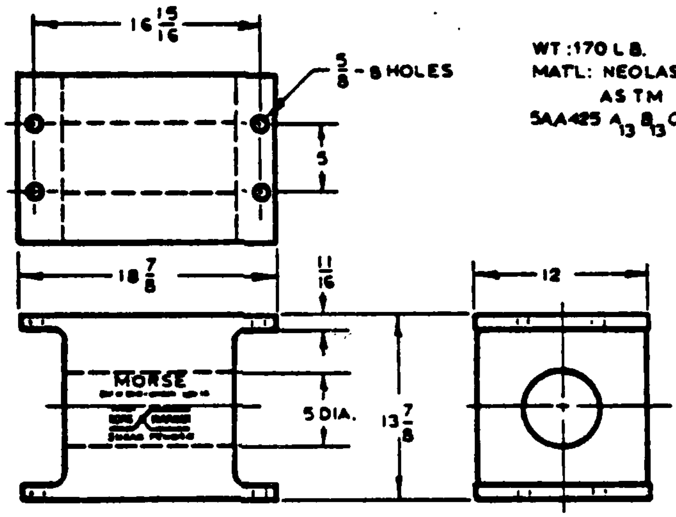
WASHER PLATE DETAIL
1/8 STEEL STOCK
4 REQ'D. / FENDER

INCH	cm.
9/16	1.43
5/8	1.59
4	10.16
10	25.40
11-5/8	29.53
14-1/8	35.88
15-3/4	40.01

10" SHEAR FENDER

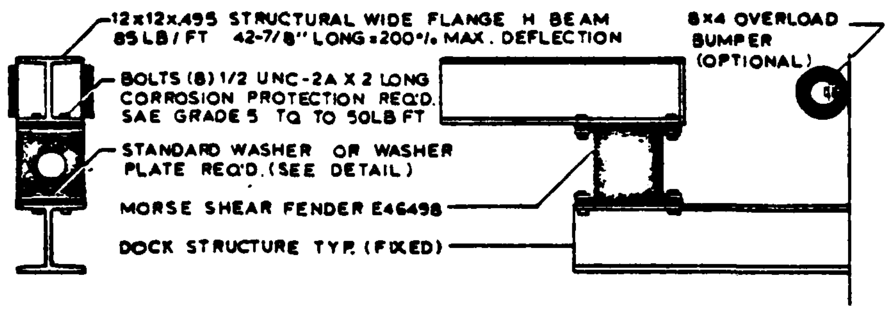


12" SHEAR FENDER • Part No. E46498 U.S. PAT. 3,763,653

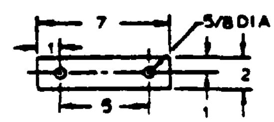


WT: 170 LB.
MAT'L: NEOLASTIC• RUBBER
ASTM D-2000
5AA425 A_{13} B_{13} C_{20} F_{17} K_{11} L_{14}

MOUNTING RECOMMENDATIONS



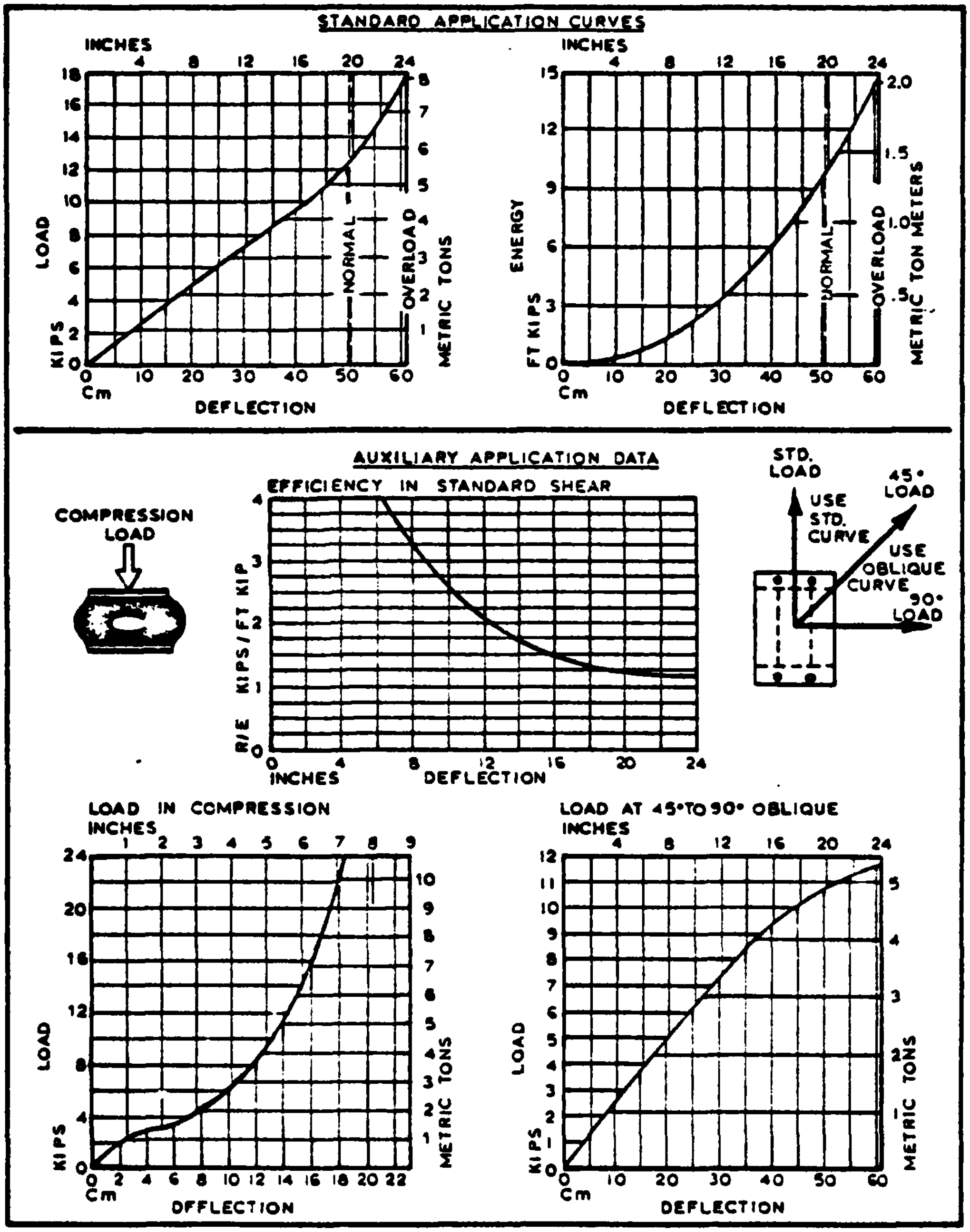
12" SHEAR FENDERS WILL SUPPORT 3 KIPS IN COMPRESSION WITH NO NOTICABLE CHANGE IN THE SHEAR REACTION



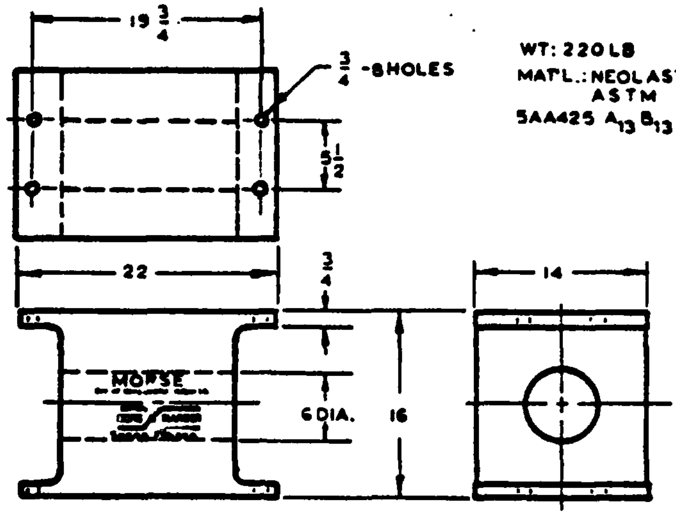
WASHER PLATE DETAIL
1/8 STEEL STOCK
4 REQ'D./FENDER

INCH	Cm.
5/8	1.59
11/16	1.75
5	12.70
12	30.48
13-7/8	35.24
16-15/16	43.02
18-7/8	47.94

12" SHEAR FENDER

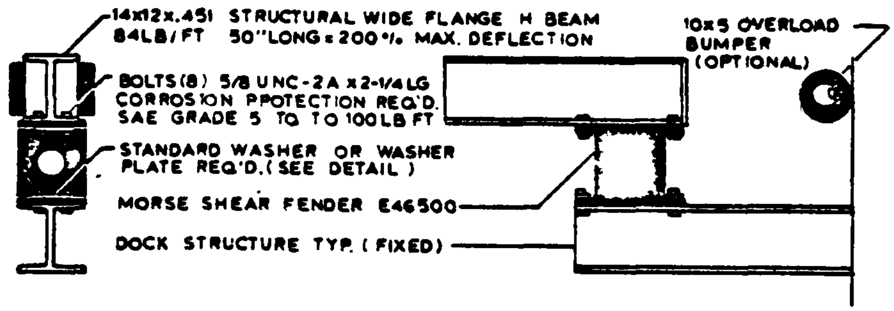


14" SHEAR FENDER • Part No. E46500 U.S. PAT. 3,763,653



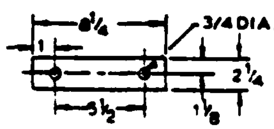
WT: 220 LB
MAT'L.: NEOLASTIC® RUBBER
ASTM D-2000
5AA425 A_{13} B_{13} C_{20} F_{17} K_{11} L_{14}

MOUNTING RECOMMENDATIONS



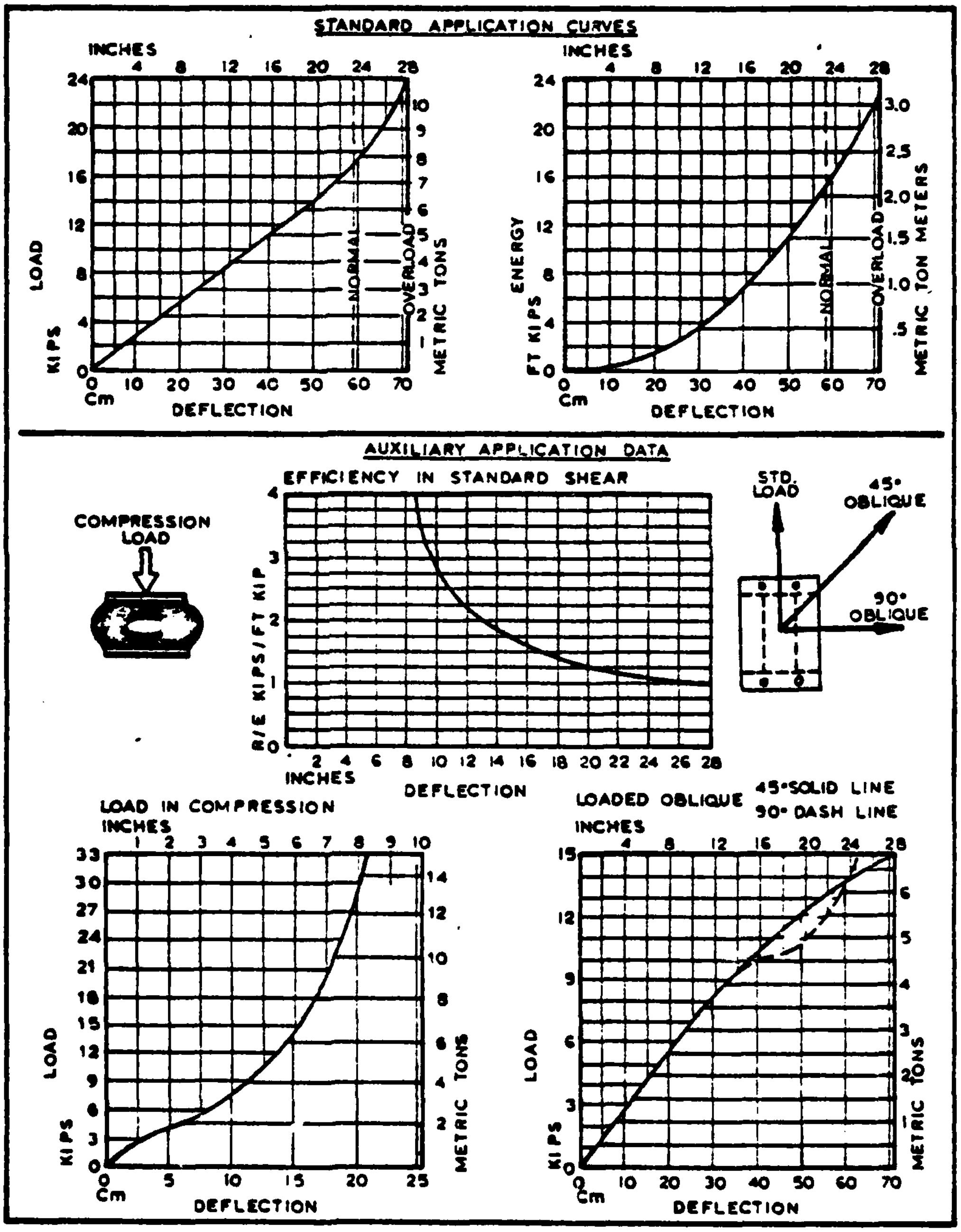
14" SHEAR FENDERS WILL SUPPORT 4 KIPS IN COMPRESSION WITH NO NOTICABLE CHANGE IN THE SHEAR REACTION

INCH	Cm.
3/4	1.91
5-1/2	13.97
6	15.24
14	35.56
16	40.64
19-3/4	50.17
22	55.88

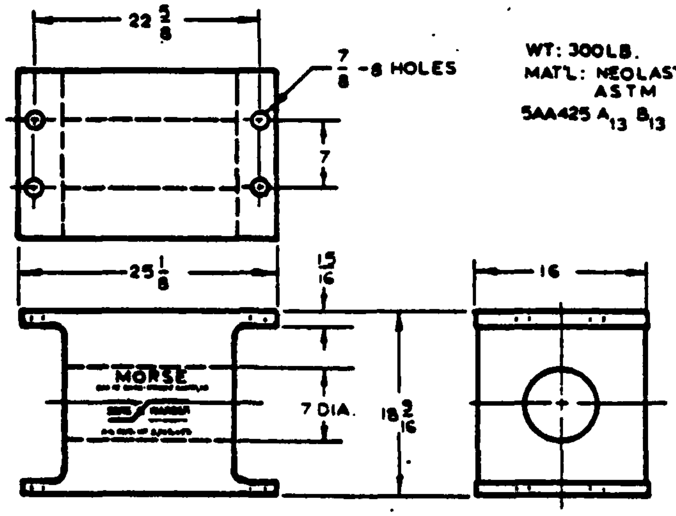


WASHER PLATE DETAIL
3/16 STEEL STOCK
4 REQ'D. / FENDER

14" SHEAR FENDER

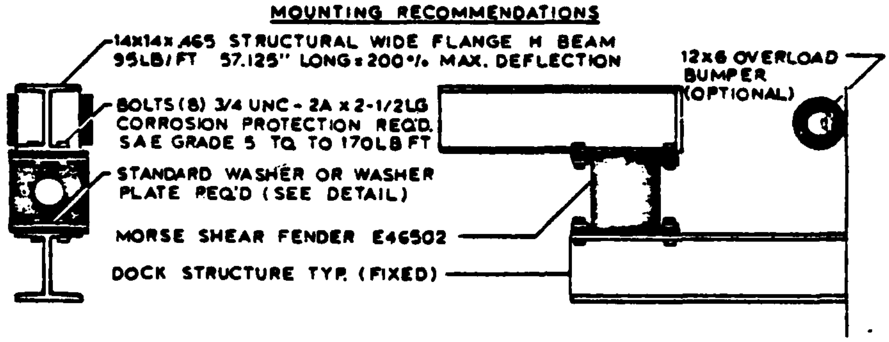


16" SHEAR FENDER • Part No. E46502 U.S. PAT. 3,763,653

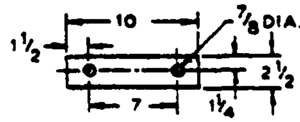


WT: 300LB.
MAT'L: NEOLASTIC® RUBBER
ASTM D-2000
5AA425 A_{13} B_{13} C_{20} F_{17} K_{11} L_{14}

MOUNTING RECOMMENDATIONS



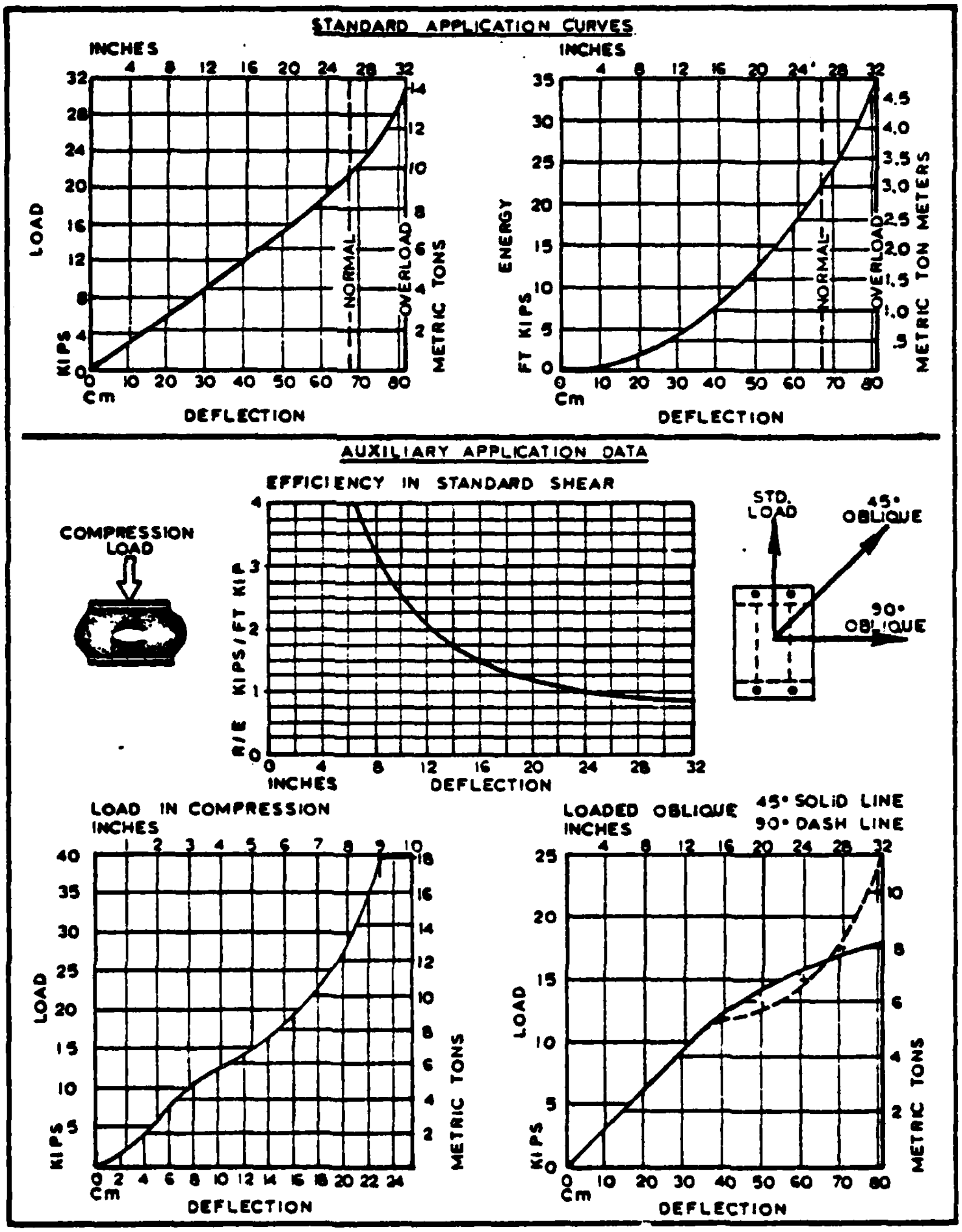
16" SHEAR FENDERS
WILL SUPPORT 5 KIPS
IN COMPRESSION WITH
NO NOTICABLE CHANGE
IN THE SHEAR REACTION



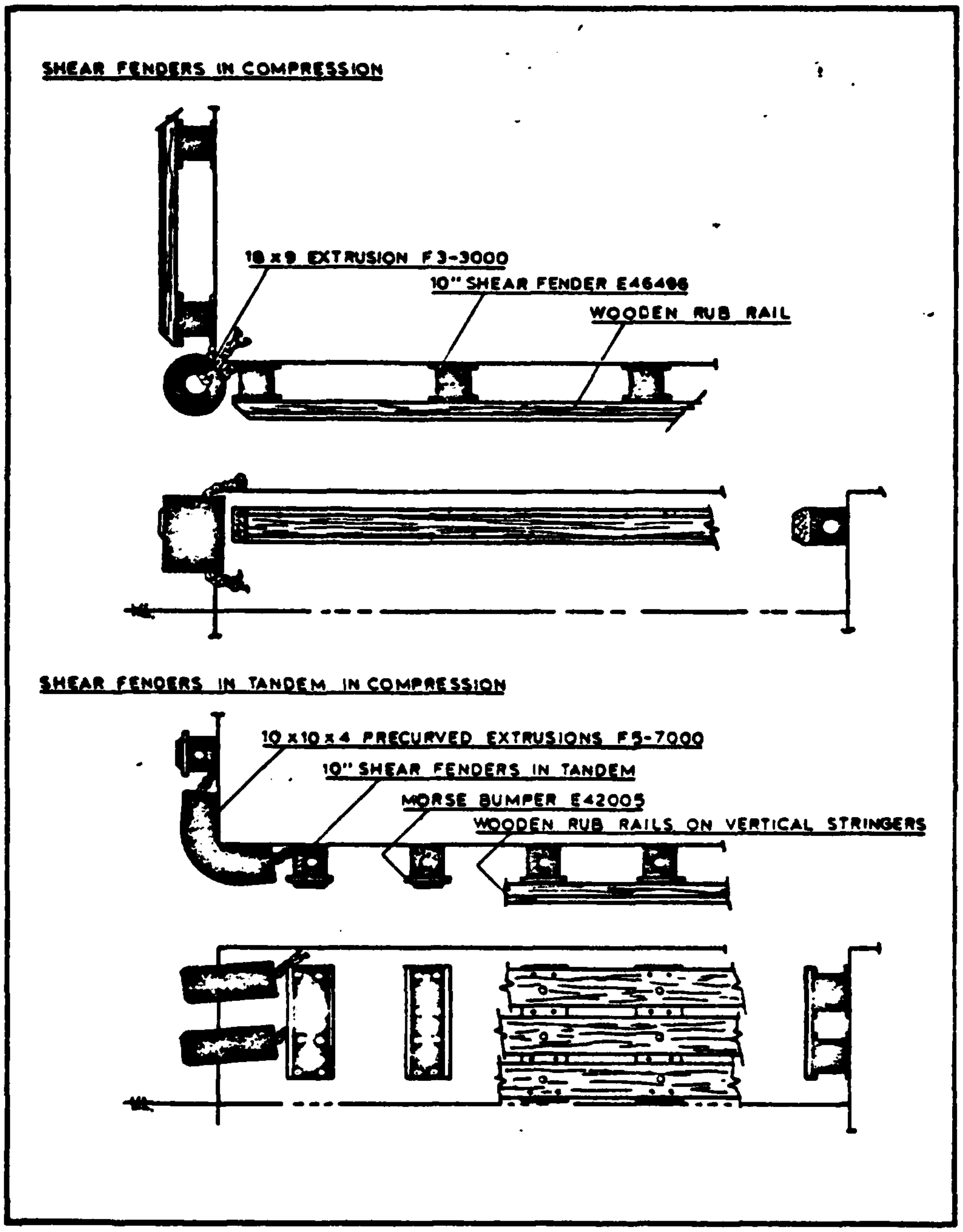
WASHER PLATE DETAIL
1/4 STEEL STOCK
4 REQ'D./FENDER

INCH	Cm.
7/8	2.22
15/16	2.38
7	17.78
16	40.64
18-9/16	47.15
22-5/8	57.47
25-1/8	63.82

16" SHEAR FENDER

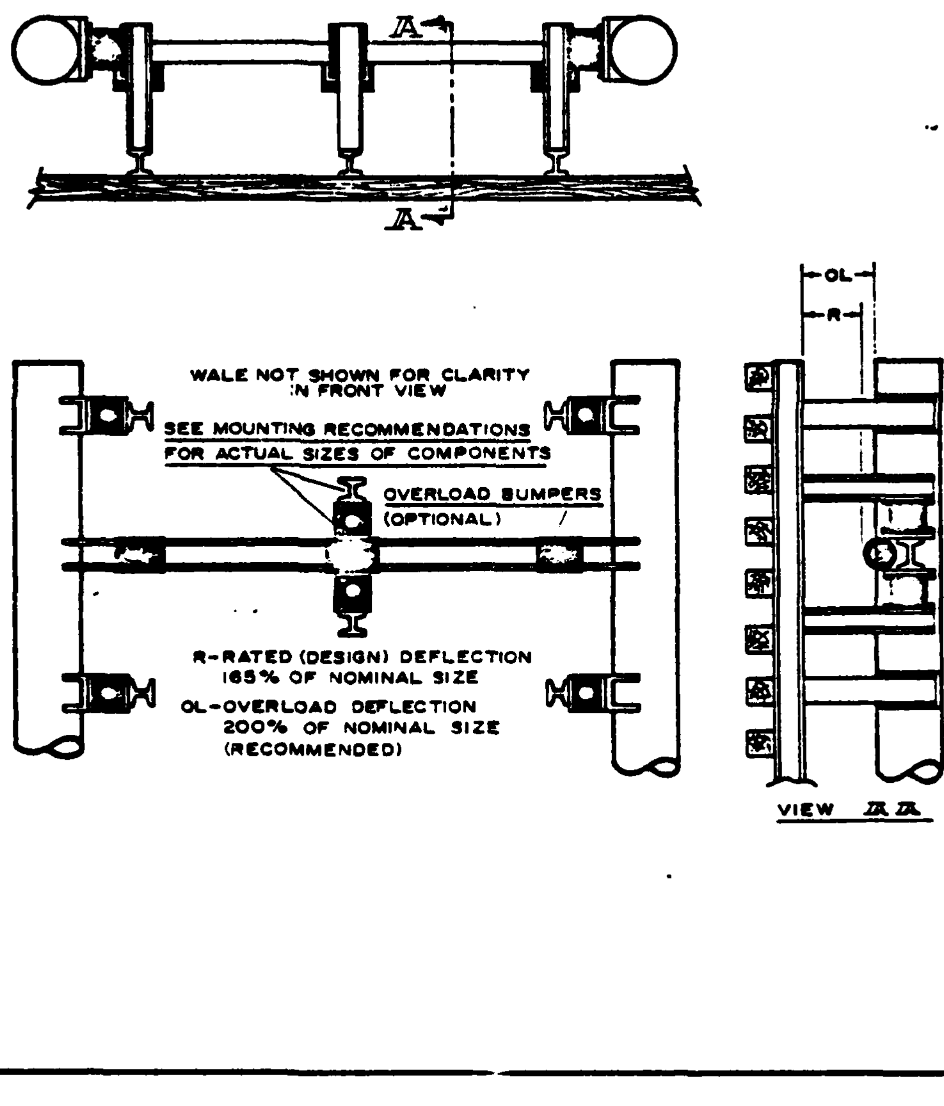


TYPICAL APPLICATIONS



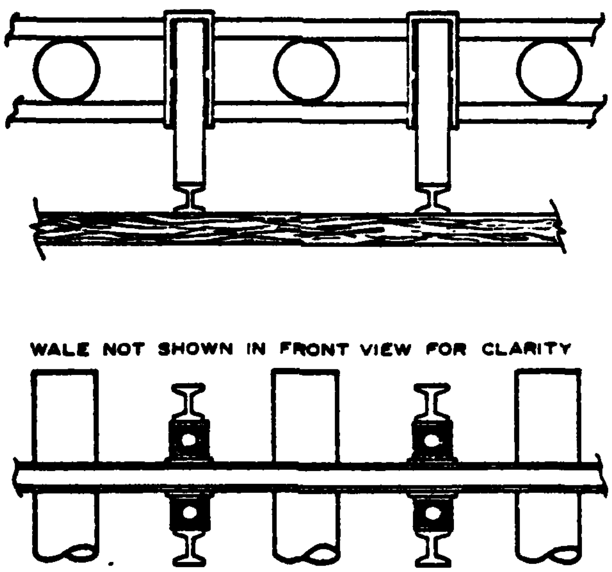
TYPICAL APPLICATIONS

SHEAR FENDERS MOUNTED HORIZONTAL OR VERTICAL

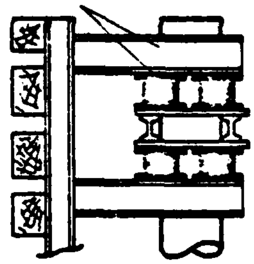


TYPICAL APPLICATIONS

SHEAR FENDERS MOUNTED IN TANDEM

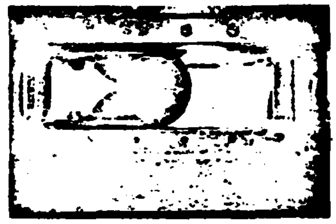


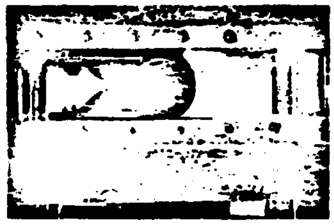
SEE MOUNTING RECOMMENDATIONS FOR ACTUAL SIZE OF COMPONENTS.

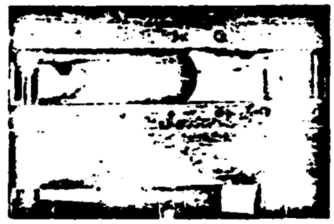



Zero deflection


25% deflection


50% deflection


60% deflection


70% deflection

BUCKLING COLUMN FENDERS

GENERAL

The Buckling Column, like the Shear Fender, is an efficient device for absorbing berthing energy (loads) of large vessels while transmitting relatively low reaction loads to the dock structure. The Buckling Column type fender can be installed where the space behind the dock face is limited. Solid walls, where the Column is face mounted and supported by pile or chain is an excellent example of a dock where all the energy must be absorbed between the dock and the wale. For such cases, Buckling Columns are an ideal choice.

Buckling Columns can also be used in combination with other absorbers such as Shear Fenders or Extrusions to take advantage of the features of the various types of systems. When used to its designed maximum capacity, the Buckling Column is extremely efficient, but if overloads occur, transmitted loads increase rapidly after the rated deflection is reached. (See application curves). For this reason, care should be taken in designs where a gross overload could cause major damage to a berthing vessel or the docking facility.

Buckling Columns are designed to buckle in a known direction. This allows Columns to be mounted in pairs or quadrant groupings to meet design requirements. Sometimes it is more feasible to use a pair of smaller Columns in place of a single large Column. A pair of smaller Columns will transmit a lower load at two points of support yet in total will absorb the same energy as a single large Column. Thus, the load may be split while the energy absorbed remains constant.

THE MORSE BUCKLING COLUMN FENDER

- Each Morse Buckling Column Fender is a molded rectangular rubber column of Neolastic® rubber with metal mounting plates embedded in and bonded to the ends, to create an integral unit that is resistant to ozone, sunlight, temperature extremes, marine growth, wear, and abrasion.
- Before shipment from the Morse Plant, each Buckling Column is cycled (see photos) to insure a product free from hidden manufacturing defects.
- Morse Buckling Columns are directly interchangeable with units of other manufacturers in the same size.
- Sizes range from 12" to 48" with efficiency rating (R/E) as low as 0.64.
- All metal is corrosion protected for long service life.

SPECIFICATION: BUCKLING COLUMN

The Morse Buckling Column Fender, Part No. (See Product Dimension Sheet), shall be an assembly consisting of:

1. A rubber rectangular column made of ASTM D-2000 NEOLASTIC rubber and meeting the following ASTM test values 3AA725, B_{13}, C_{20}, F_{17}, K_{11}, L_{14}
2. Metal insert plates embedded in and bonded to that column, such plates being completely encased in rubber for corrosion protection.

Design Load (Reaction) shall be ________ Kips or Met. Tons (See Prod. Data Curve)

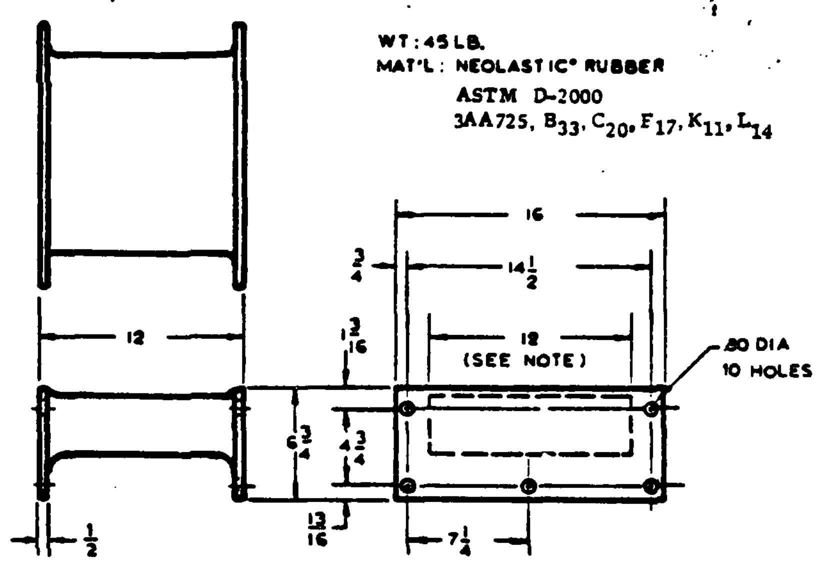
Designed Energy Absorption shall be ________ Ft. Kips or Met. In Mets. (See Product Data Curve)

Designed Deflection shall be ________ Inches or Cm. to a maximum of ________ Inches or Cm

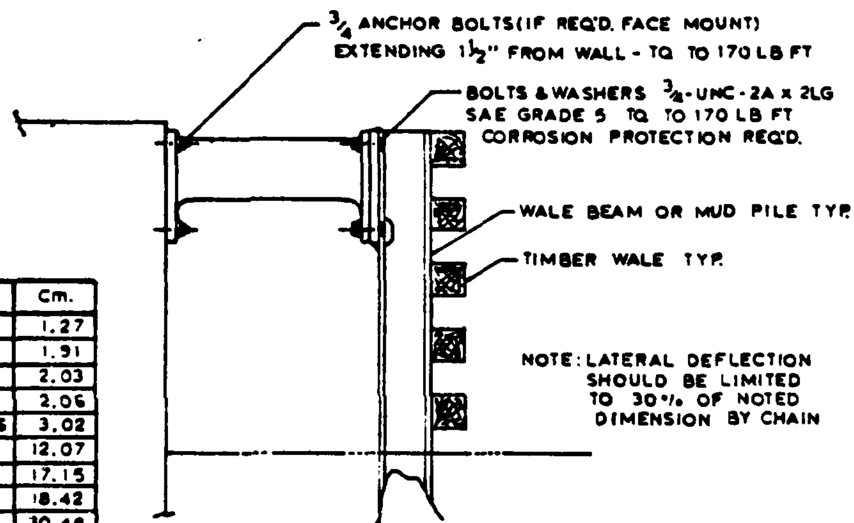
Specifications subject to change without notice. Certified prints provided with quotations on request.

12" BUCKLING COLUMN • Part Nos. E46003 & E46005

WT: 45 LB.
MAT'L: NEOLASTIC® RUBBER
ASTM D-2000
3AA725, B_{33}, C_{20}, F_{17}, K_{11}, L_{14}



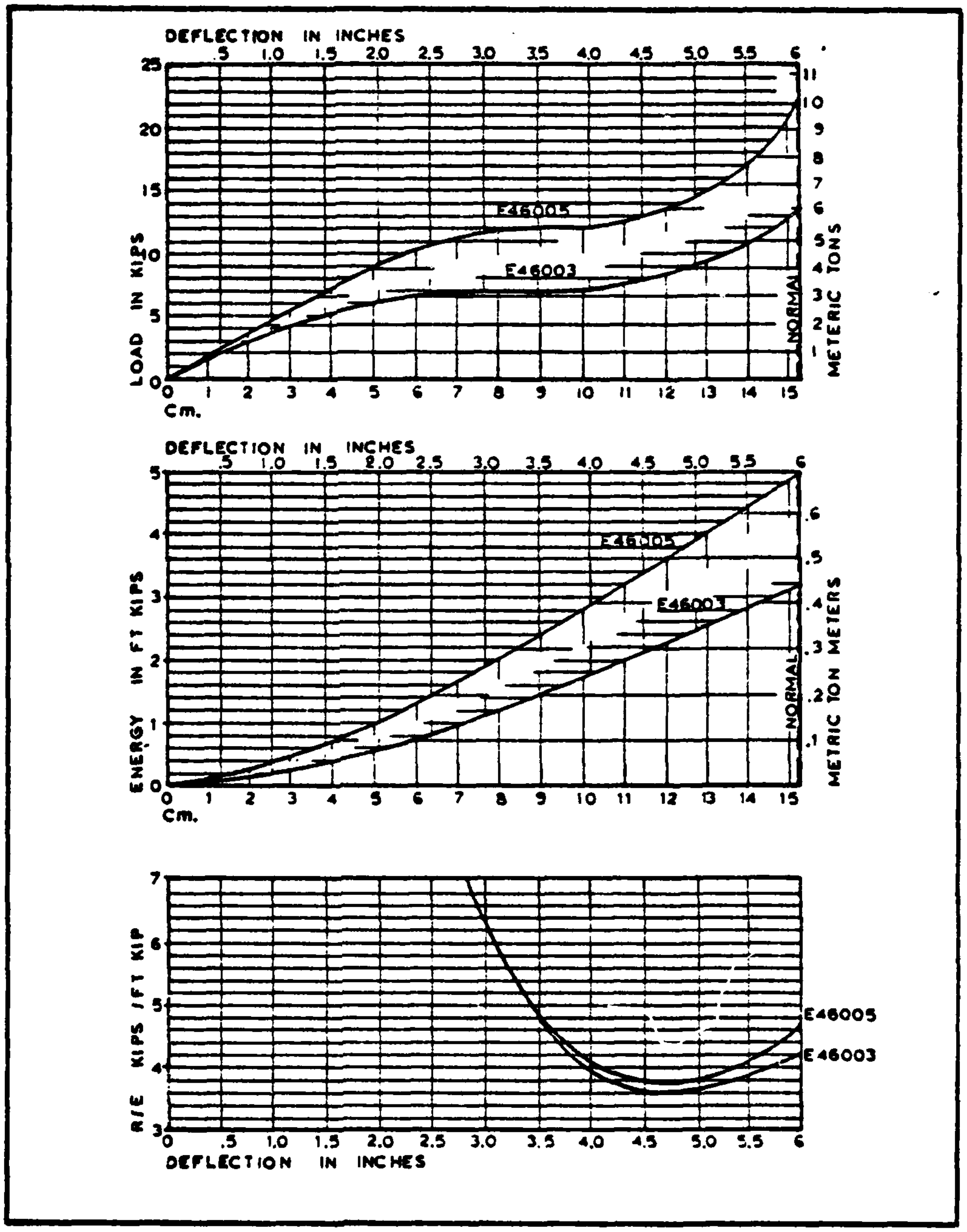
MOUNTING RECOMMENDATIONS



INCH	Cm.
1/2	1.27
3/4	1.91
.80	2.03
13/16	2.06
1-3/16	3.02
4-3/4	12.07
6-3/4	17.15
7-1/4	18.42
12	30.48
14-1/2	36.83
16	40.64

NOTE: LATERAL DEFLECTION SHOULD BE LIMITED TO 30% OF NOTED DIMENSION BY CHAIN

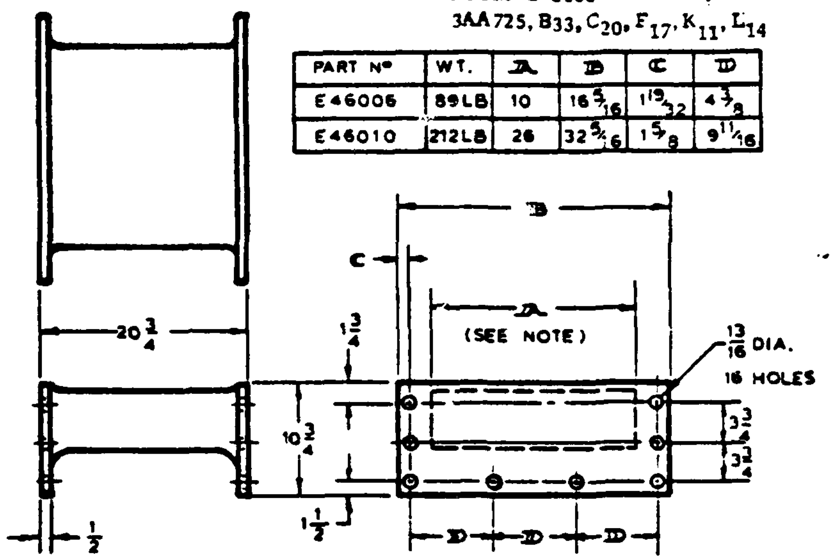
12" BUCKLING COLUMN APPLICATION CURVES



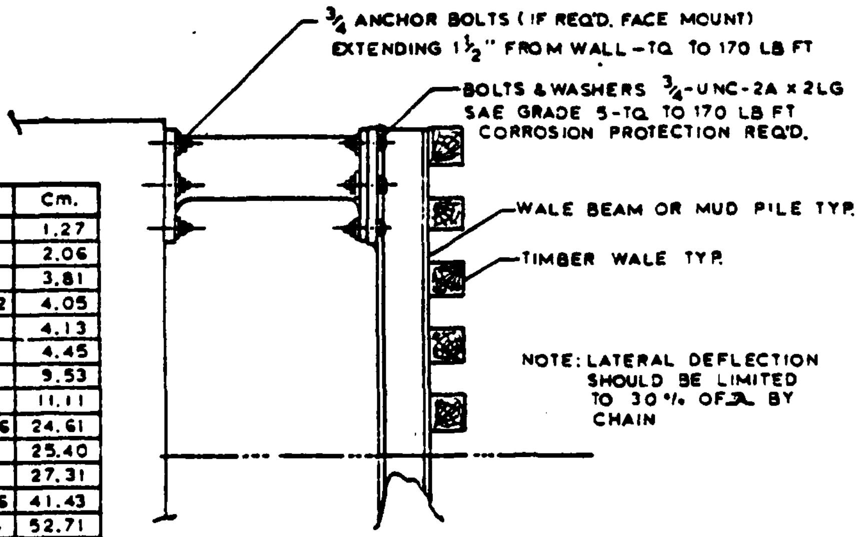
20" BUCKLING COLUMN • Part Nos. E46006 & E46010

MAT'L: NEOLASTIC® RUBBER
ASTM D-2000
3AA725, B_{33}, C_{20}, F_{17}, K_{11}, L_{14}

PART N°	WT.	A	B	C	D
E46006	89LB	10	16 5/16	1 19/32	4 3/8
E46010	212LB	26	32 5/16	1 5/8	9 11/16



MOUNTING RECOMMENDATIONS



INCH	Cm.
1/2	1.27
13/16	2.06
1-1/2	3.81
1-19/32	4.05
1-5/8	4.13
1-3/4	4.45
3-3/4	9.53
4-3/8	11.11
9-11/16	24.61
10	25.40
10-3/4	27.31
16-5/16	41.43
20-3/4	52.71
26	66.04
32-5/16	82.07

NOTE: LATERAL DEFLECTION SHOULD BE LIMITED TO 30% OF A BY CHAIN

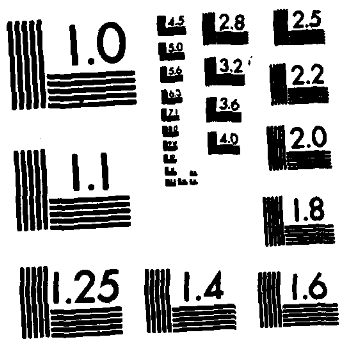
AD-A124 597 SYNTHESIS OF A COLLISION TOLERANT FIXED NAVIGATION MARKER SYSTEM(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA M R MILLER OCT 82 2/2

UNCLASSIFIED F/G 13/10 NL

END

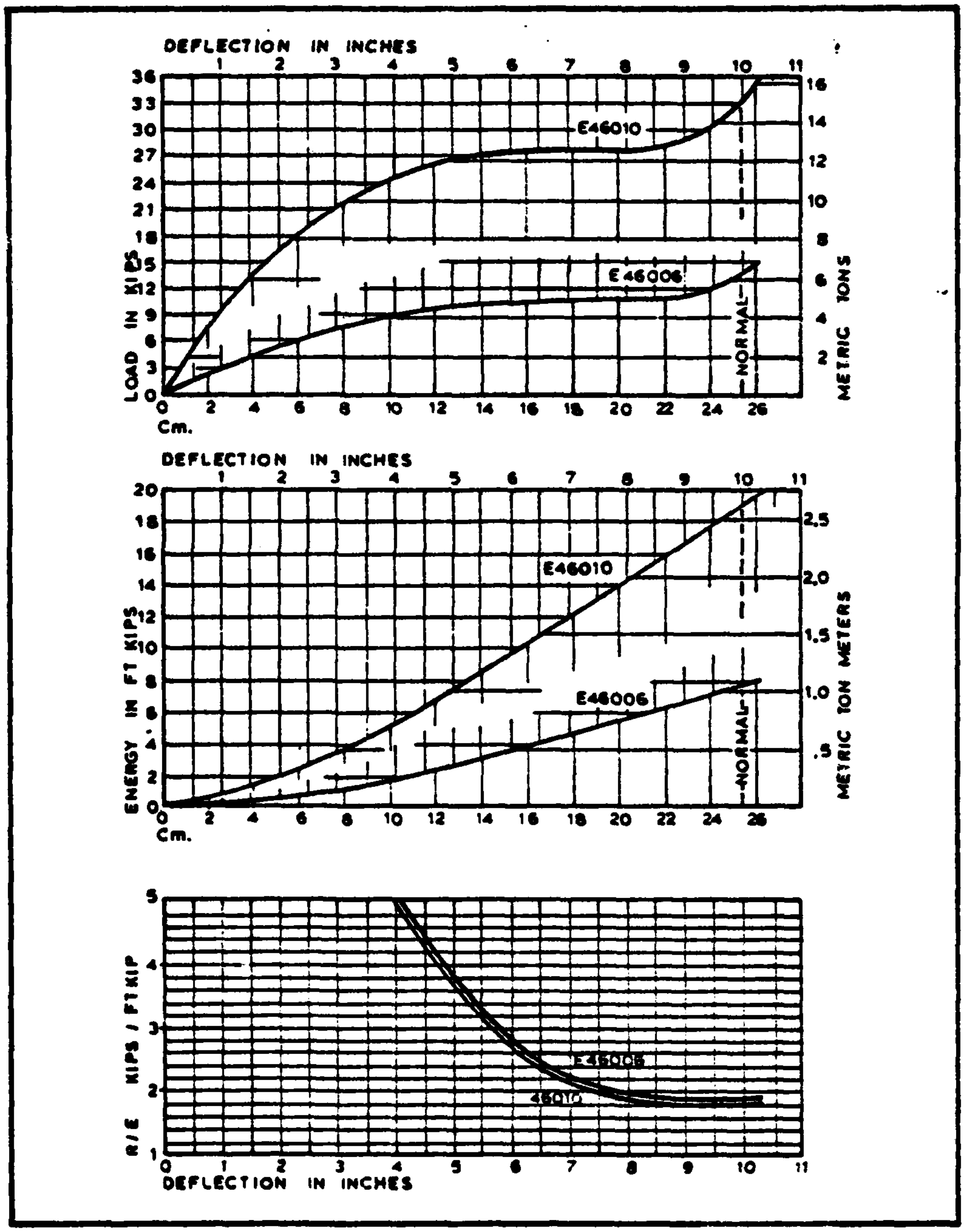
FILMED

DTIC

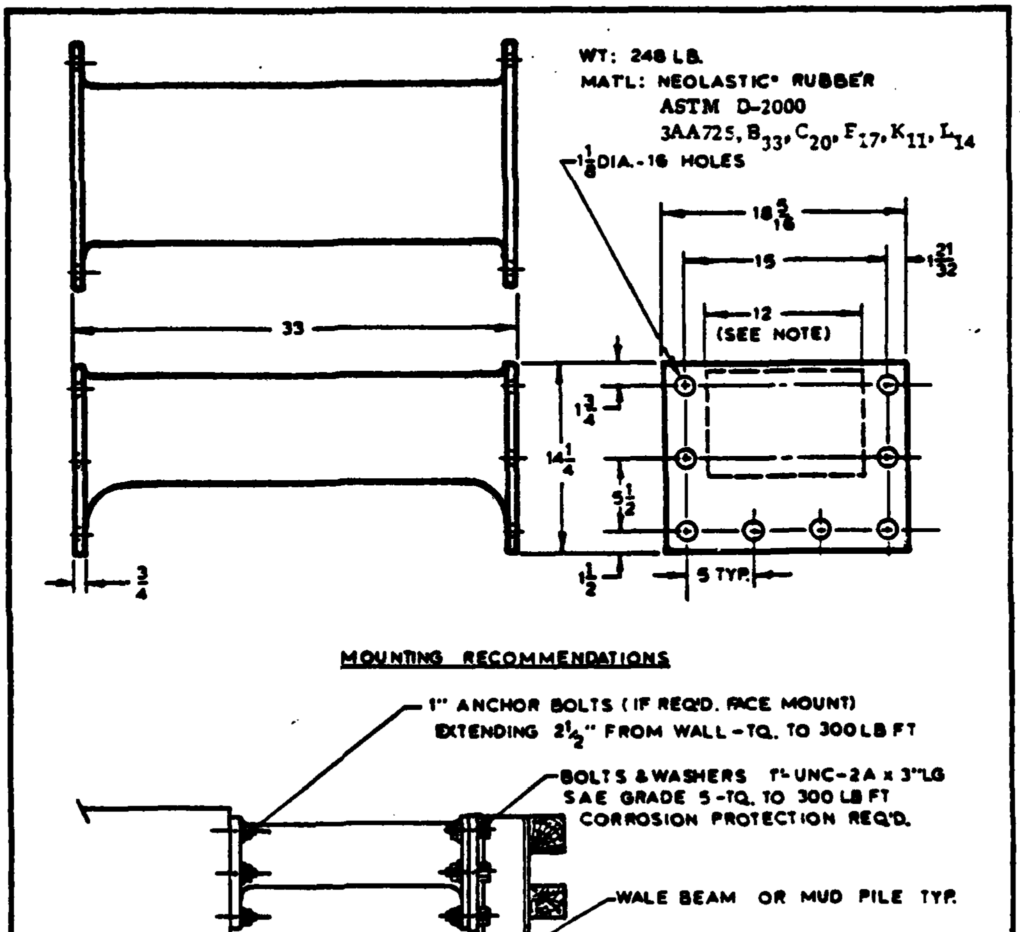


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

20" BUCKLING COLUMN APPLICATION CURVES

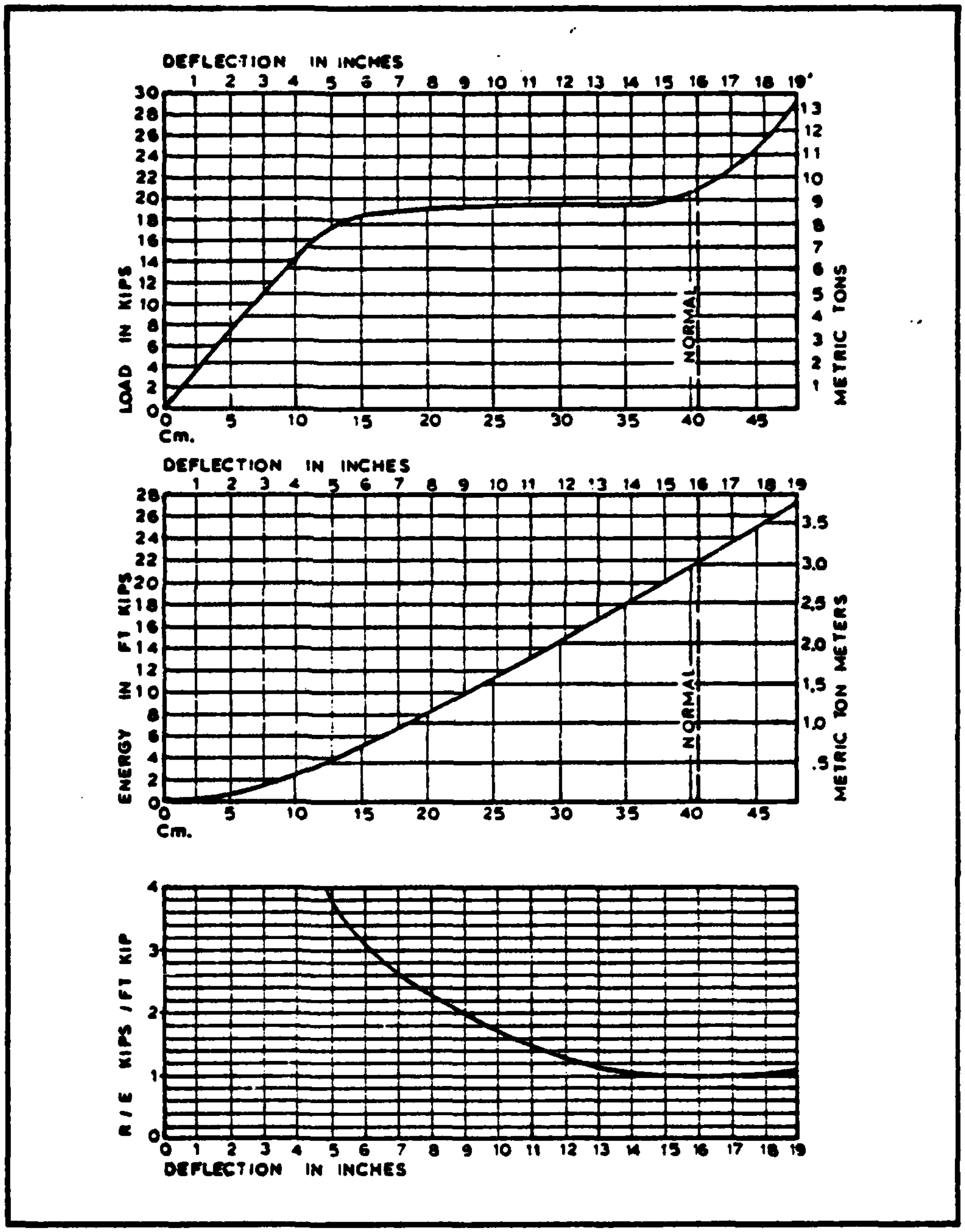


33" BUCKLING COLUMN • Part No. E46011

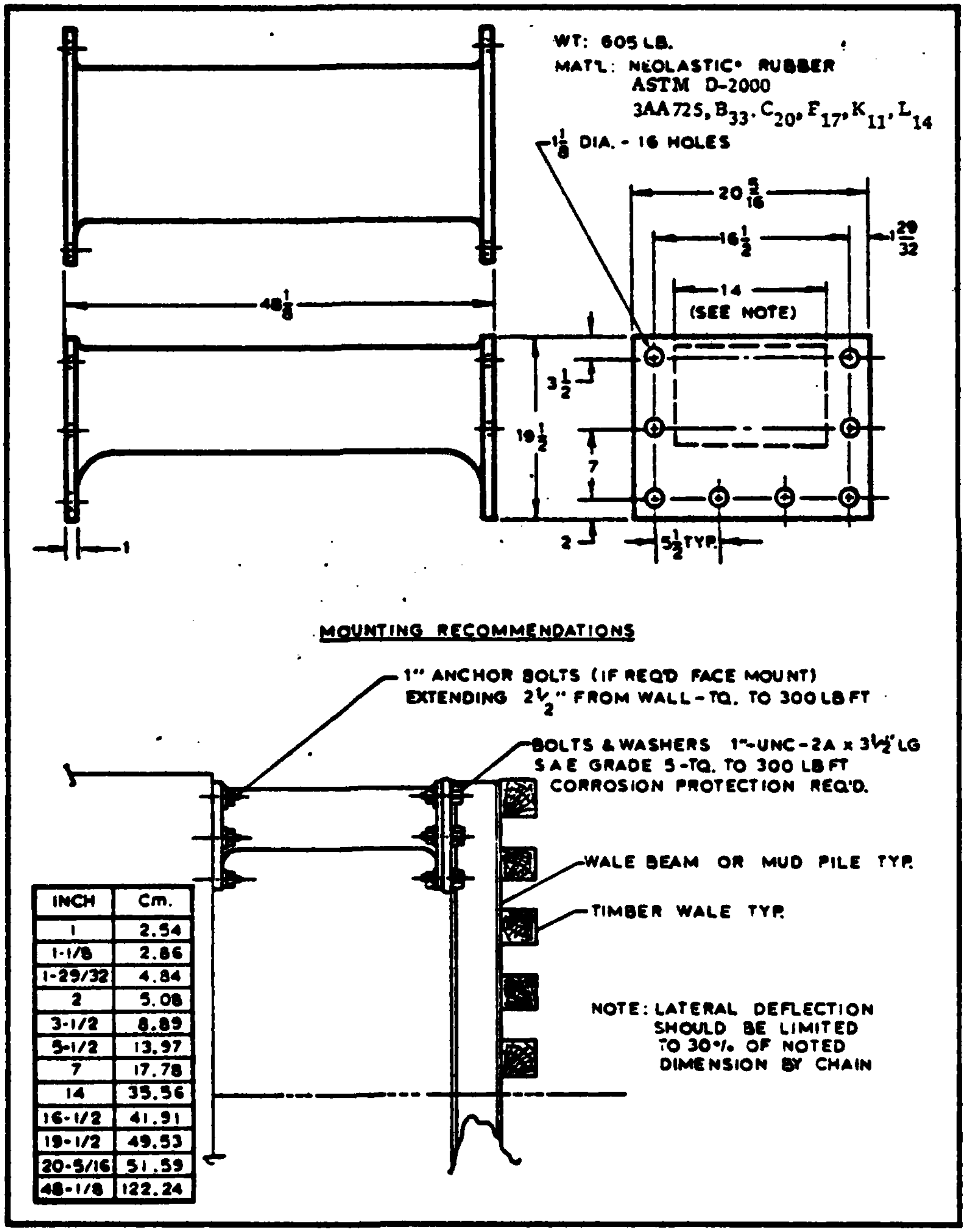


INCH	Cm.
3/4	1.91
1-1/8	2.86
1-1/2	3.81
1-21/32	4.21
1-3/4	4.45
5	12.70
5-1/2	13.97
12	30.48
14-1/4	36.20
15	38.10
18-5/16	46.51
33	83.82

33" BUCKLING COLUMN APPLICATION CURVES

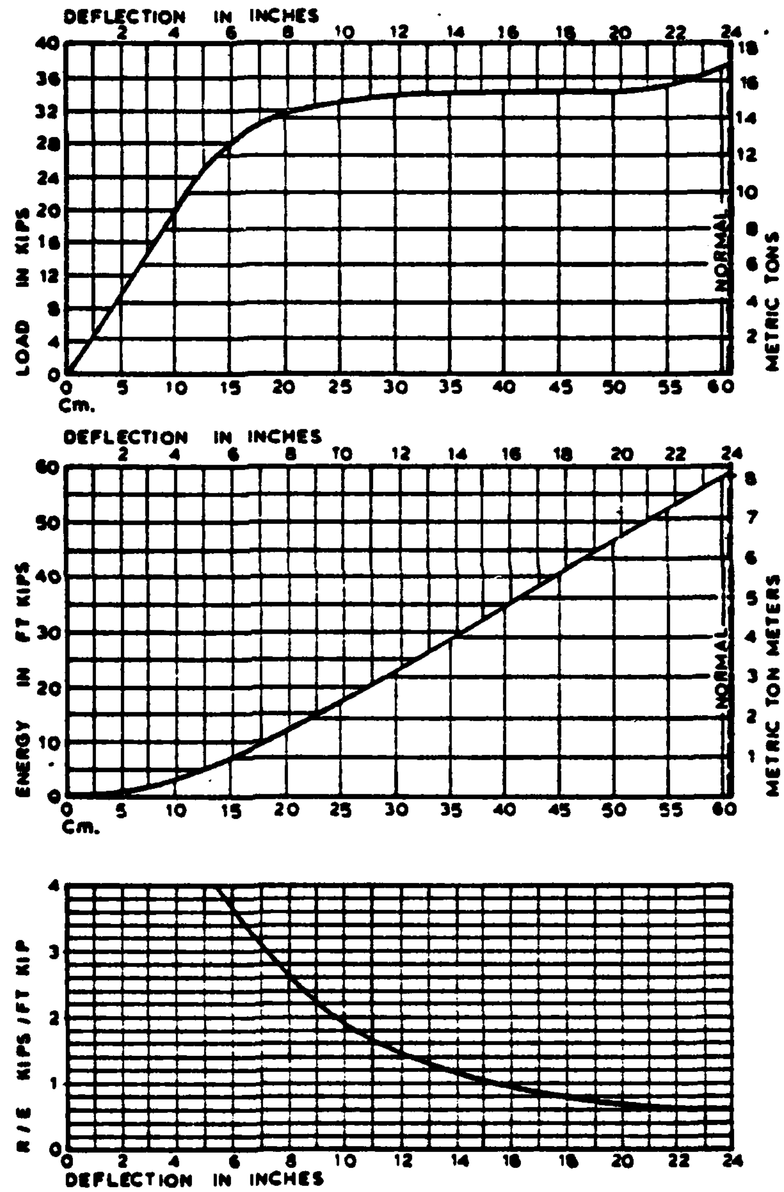


48" BUCKLING COLUMN • Part No. E46018

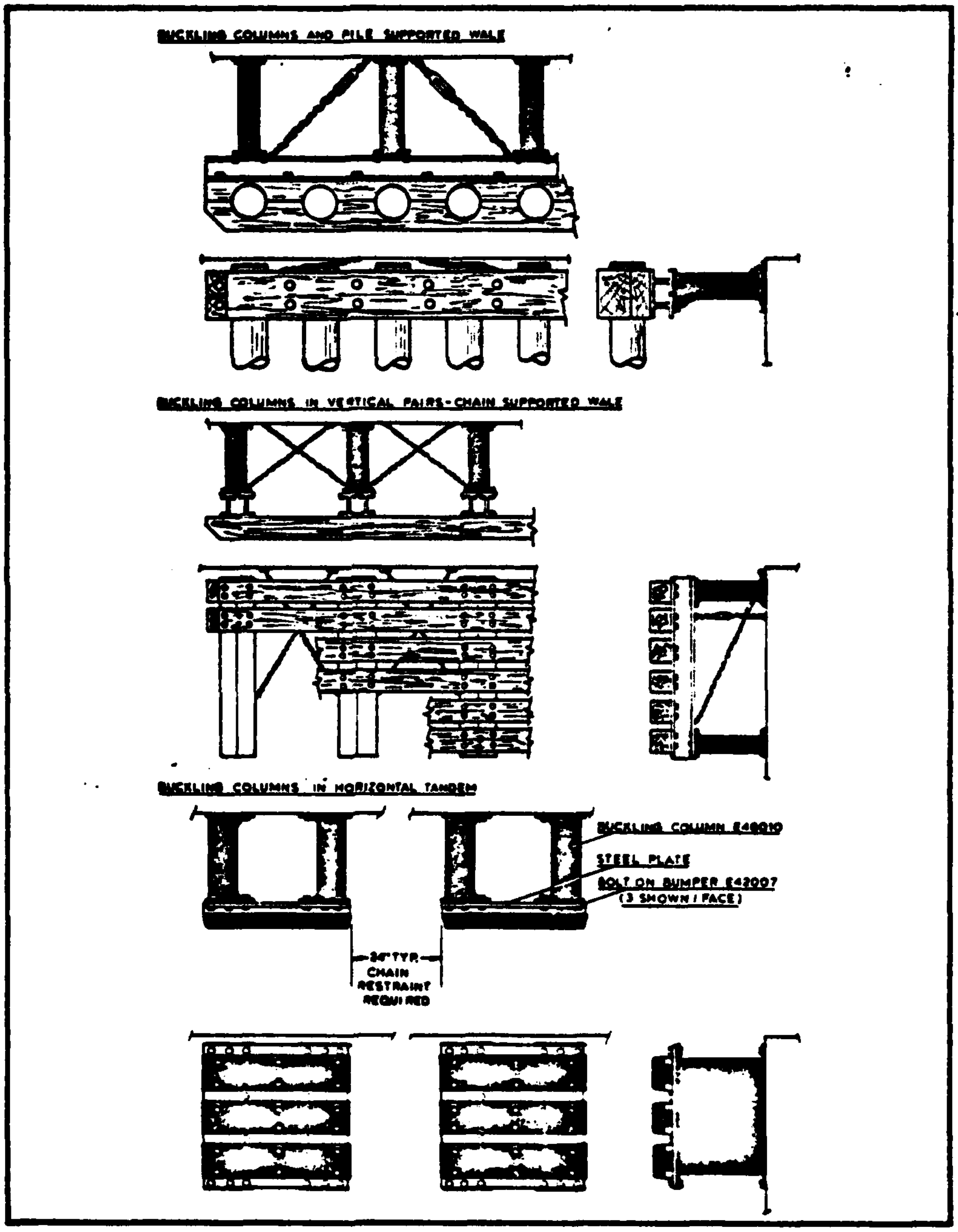


INCH	Cm.
1	2.54
1-1/8	2.86
1-29/32	4.84
2	5.08
3-1/2	8.89
5-1/2	13.97
7	17.78
14	35.56
16-1/2	41.91
19-1/2	49.53
20-5/16	51.59
48-1/8	122.24

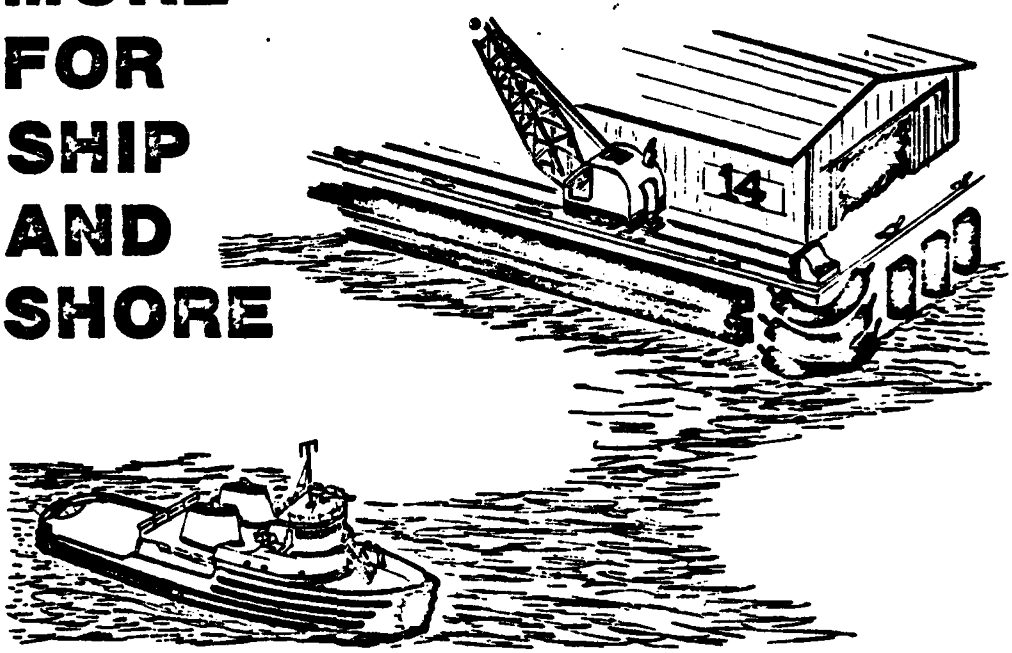
48" BUCKLING COLUMN APPLICATION CURVES



TYPICAL APPLICATIONS



MORE FOR SHIP AND SHORE



EXTRUDED FENDERS

Extruded fenders are one of the most widely used forms of fender protection and come in a wide range of sizes and shapes. Although relatively inefficient when compared to other fender types, Extruded Fenders are the logical choice where structures are rigid, where the relative motion between rubbing surface and fender is lateral, or where vessel size is small and the energy levels are low.

For this reason Extruded Fenders are found in both dock applications and as bumpers for tugs, barges, work boats and larger pleasure craft. Extruded fenders perform their protective function by acting as a soft interface between a vessel and dock or between two vessels.

Extruded fenders may be bolted, hung on chain, or clamped to flat dock walls or hulls.

Extruded fenders can be precurved during fabrication to fit special shape requirements or attachment methods.

Mounting holes can be drilled on factory order or can be drilled on site with a standard (⅛" oversize) twist drill at 250 rpm. The drill should be sharpened to 120° included angle and lubricated with water or green soap.

Standard extruded fender tolerances are +4% on outside dimensions, +8% on inside dimensions, +½" on lengths up to 5 feet, and +1% on longer sections up to 20 feet maximum.

The standard material for extruded fenders is *Neolastic®* rubber with a durometer of 70+ 5, however, special stocks can be provided. Consult Morse Service Center for availability.

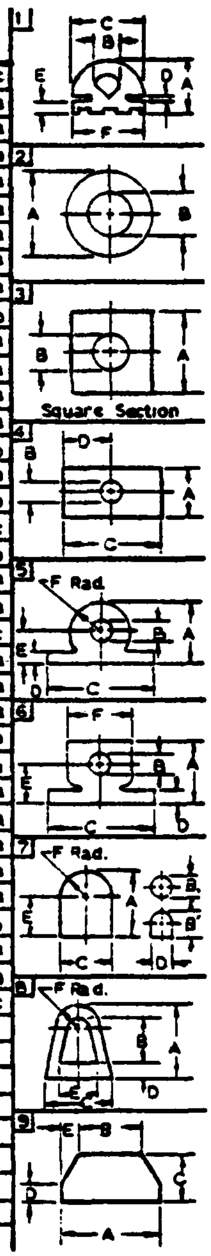
Neolastic® rubber compound for extruded fenders is resistant to oil, sunlight, ozone, temperature extremes, abrasion, and wear. It meets the following specifications MIL-R-3065-B, R.S. 720-ABD and F, ASTM D-2000-70B, and SAE designation J-2000.

Extruded shapes listed in this manual are considered standard shapes. Variations from the standard shapes can be provided. Contact Morse Service Center.

Extruded fenders, while primarily a marine product, have found many applications in industry such as truck dock bumpers, door bumpers, corner protection, rub strips, and seals.

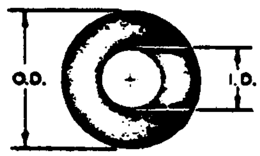
STANDARD SHAPES

REF. DWG.	A	B	C	D	E	F	WT. IN LB/FT.	PART NUMBER	REMARKS SEE NOTE
1	3 7/16	2 1/4	4 1/8	11/32	13/16	3 9/16	4.2	F1-4000	c
2	3	1 1/2					3.0	F3-0000	a
2	5	2 1/2					7.0	F3-8000	a
2	6	2					13.0	F3-9000	b
2	8	4					18.5	F3-1000	a
2	10	5					30.0	F3-2000	a
2	12	6					42.5	F3-5000	a
2	15	7 1/2					68.5	F3-6000	a
2	18	9					97.5	F3-3000	a
3	4 1/2	2 *					8.4	F6-0000	Square Bore b
3	8	3					29.5	F5-0000	a
3	10	4					45.0	F5-7000	a
3	12	5					63.0	F5-1000	a
3	14	6					81.0	F5-2000	a
3	14	6 3/4					84.3	F5-3000	b
3	6	2 1/2					15.9	F6-2000	b
3	7	3					21.4	F5-6000	b
4	2	*	4	*			4.6	F6-5000	* Solid c
4	6	1 3/4	10	3			30.0	F5-4000	b
4	8	3	10	5			36.0	F5-5000	a
4	10	4	12	6			59.0	F5-8000	a
4	2	*	12	*			10.9	F6-7000	* Solid c
5	3	1	6	3/4	1 1/2	1 1/2	4.3	F7-0000	a
5	6	3	9	1 1/2	3	3	15.5	F7-1000	a
5	12	6	18	3	6	6	58.5	F7-3000	a
5	12	6	16	3	6	6	54.0	F7-4000	b
5	10	4	16	2 1/2	5	5	48.0	F7-5000	b
6	12	6	18	3	7	12	64.0	F7-2000	a
7	6	2 1/2	5		3	3	11.5	F9-2000	"O" Bore a
7	8	3	8		4	4	22.0	F9-5000	" a
7	12	5	12		6	6	54.0	F9-3000	" a
7	8	4	8	4	4	4	22.0	F9-0000	"D" Bore a
7	12	6	12	6	6	6	52.0	F9-7000	" b
8	3 3/4	2 1/8	4 1/2	3/8	2	1 1/2	4.5	F9-4000	a
8	6	3	6 3/4	1 1/4	2 7/8	2 3/8	12.3	F9-1000	a
9	8	6	4	1	1		11.5	G1-9000	c



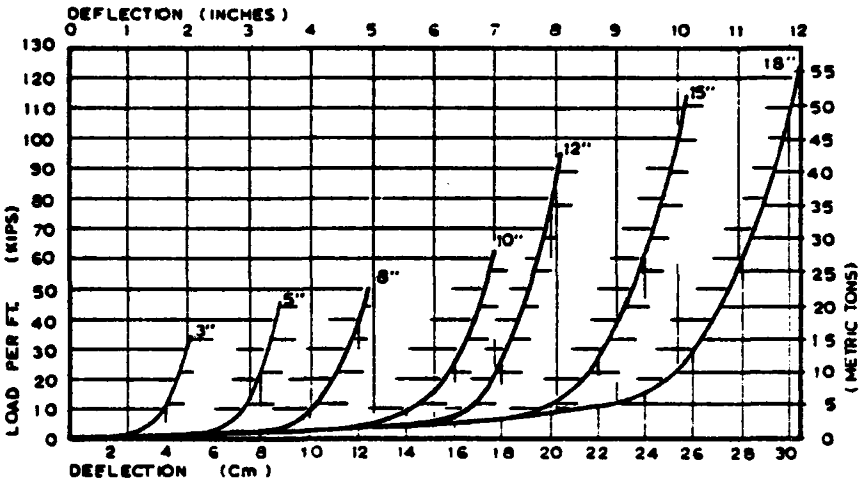
NOTE:
a. STANDARD SECTION-CURVES FOR R, E, & R/E INCLUDED Pgs.
b. NON-STANDARD SECTION-CURVES FOR R, E, & R/E UPON REQ.
c. RUB STRIP-NO CURVES

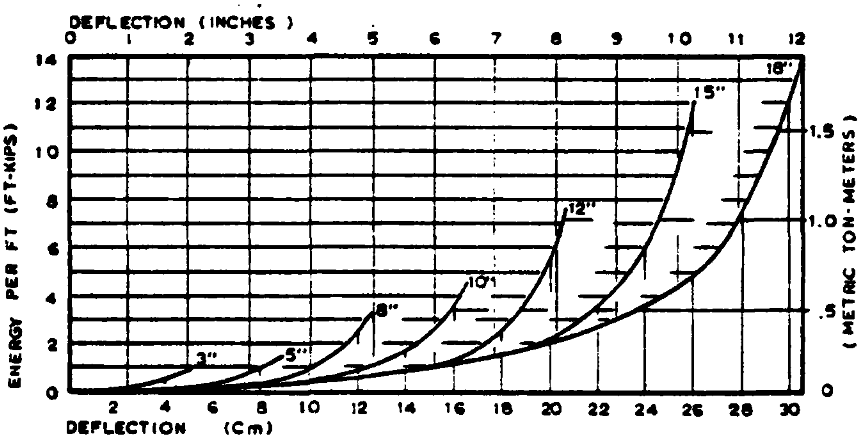
CYLINDRICAL EXTRUSION



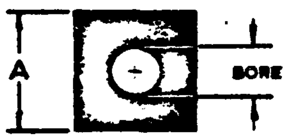
PART N°	O. D.	I. D.	Wt/Ft	R/E
F3 - 0000	3	1.5	3	14
F3 - 8000	5	2.5	7	10
F3 - 1000	8	4	18.5	10
F3 - 2000	10	5	30	6.2
F3 - 5000	12	6	42.5	5.3
F3 - 6000	15	7.5	68.5	3.5
F3 - 3000	18	9	97.5	2.9
UNITS	INCHES		lbs	KIP/FT KIP

APPROXIMATE LOAD/ENERGY, DEFLECTION CURVES FOR MORSE STANDARD CYLINDRICALS





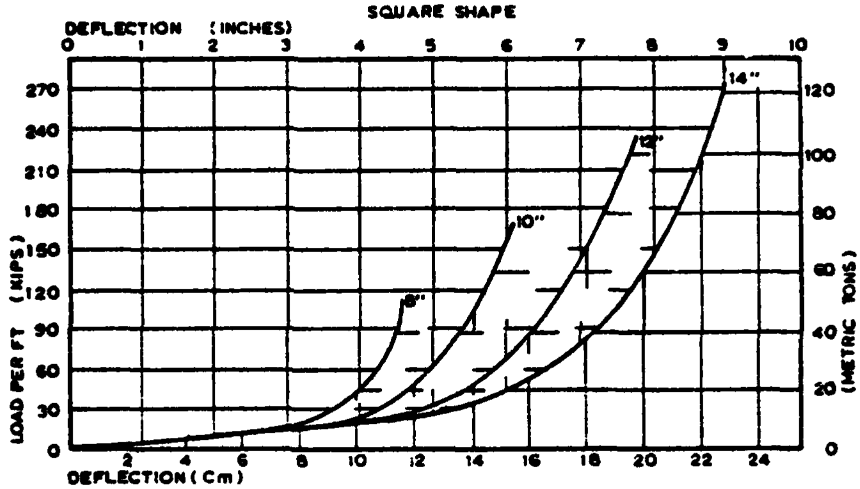
SQUARE EXTRUSION

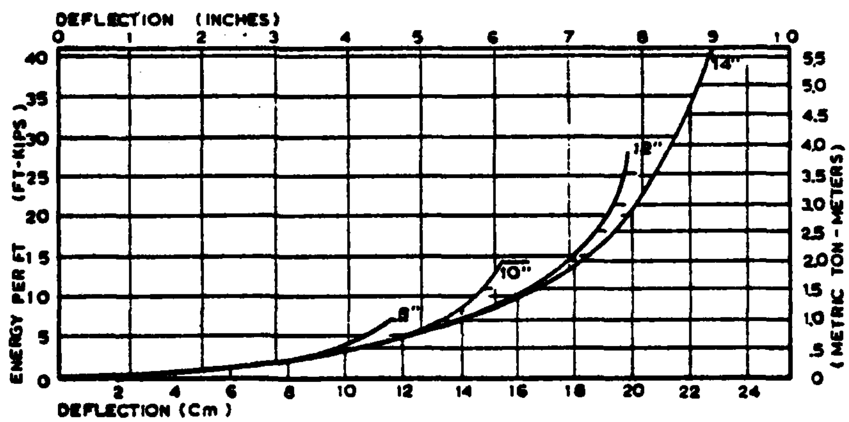


SQUARE SECTION

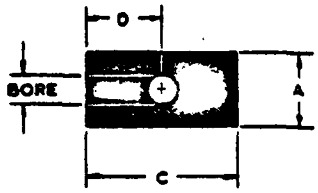
PART Nº	A	BORE	Wt/Ft	R/E
F5 -0000	8	3	29.5	10
F5 -7000	10	4	45	8.5
F5 -1000	12	5	63	7
F5 -2000	14	6	81	3.7
UNITS	INCHES		lbs	KIP/FT KIP

APPROXIMATE LOAD/ENERGY, DEFLECTION CURVES FOR MORSE STANDARD SQUARE SHAPE



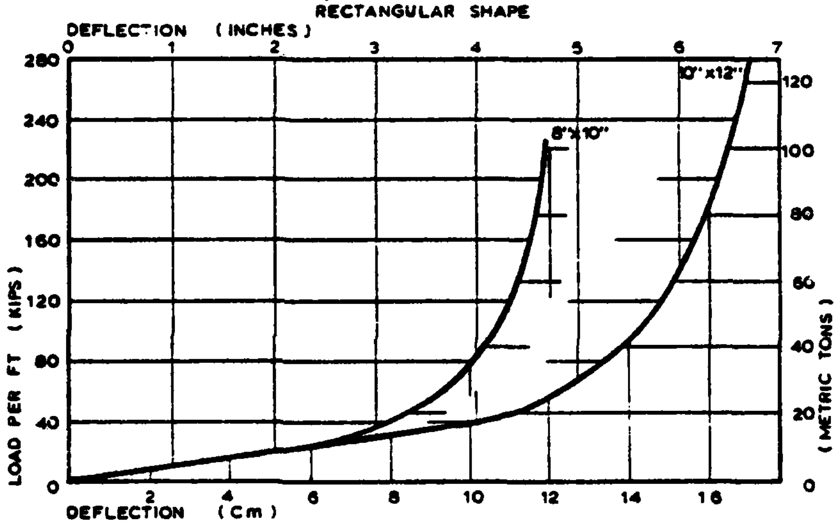


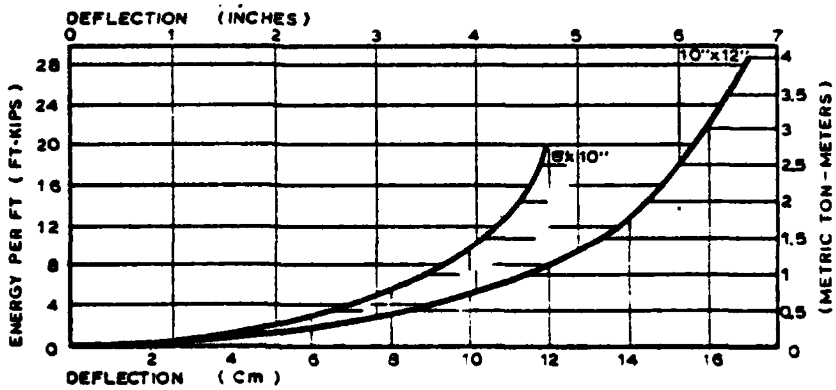
RECTANGULAR EXTRUSION



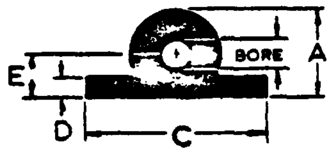
PART N°	A	BORE	C	D	Wt / Ft	R / E
F5-5000	8	3	10	5	36	8.3
F5-6000	10	4	12	6	59	7.4
UNITS	INCHES				lbs	KIP/FT KIP

APPROXIMATE LOAD/ENERGY, DEFLECTION CURVES FOR MORSE STANDARD RECTANGULAR SHAPE



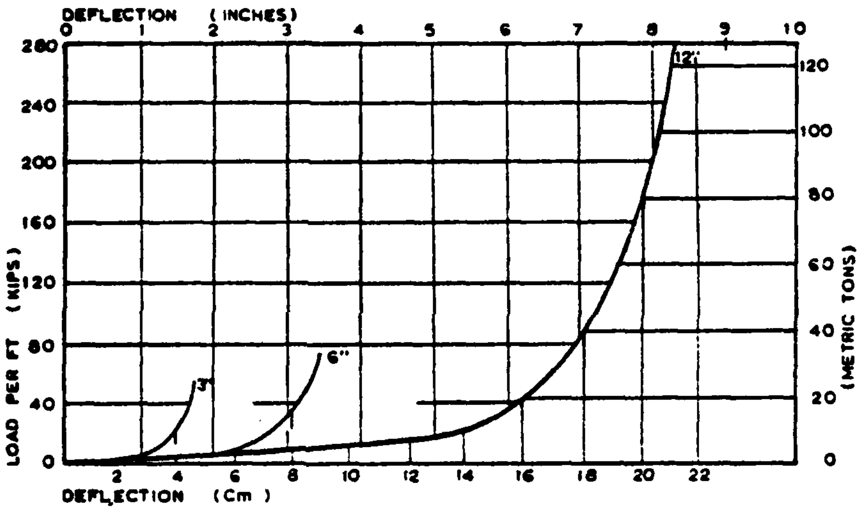


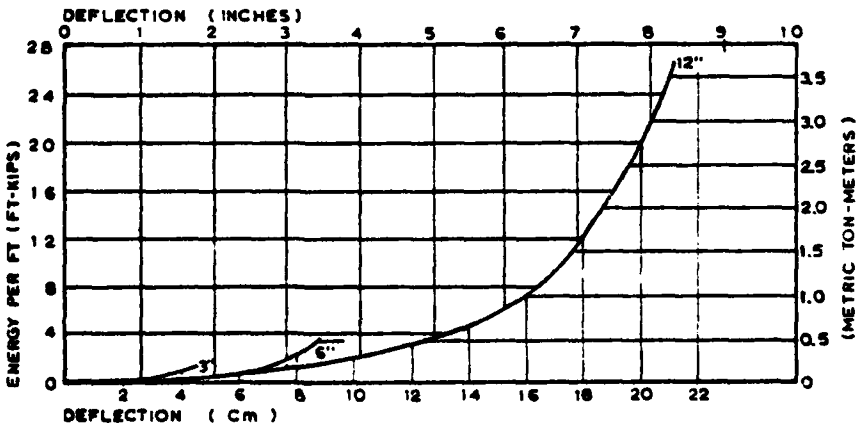
CYLINDRICAL WING EXTRUSION



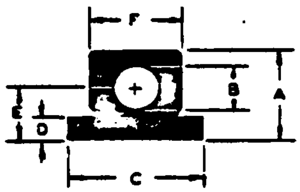
PART No	A	BORE	C	D	E	Wt/Ft	R/E
F7-0000	3	1	6	.75	1.5	4.3	25
F7-1000	6	3	9	1.5	3	15.5	13.5
F7-3000	12	6	18	3	6	58.5	6.3
UNITS	INCHES					lbs	[illegible]

APPROXIMATE LOAD/ENERGY, DEFLECTION CURVES FOR MORSE STANDARD CYLINDRICAL WING



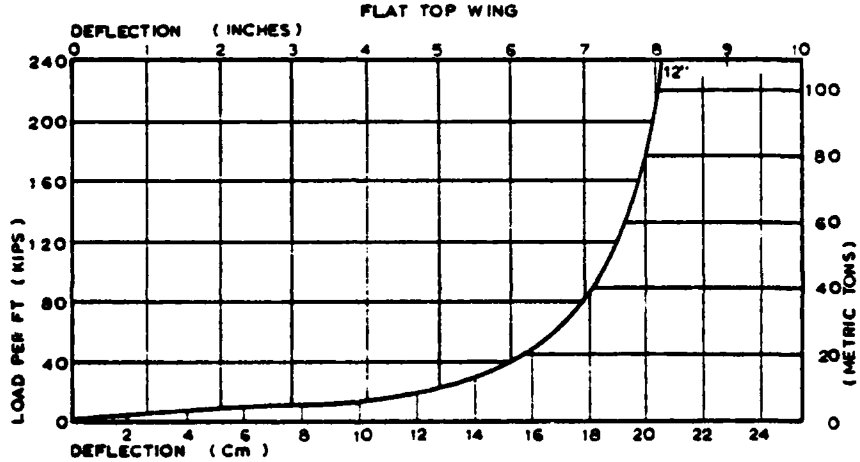


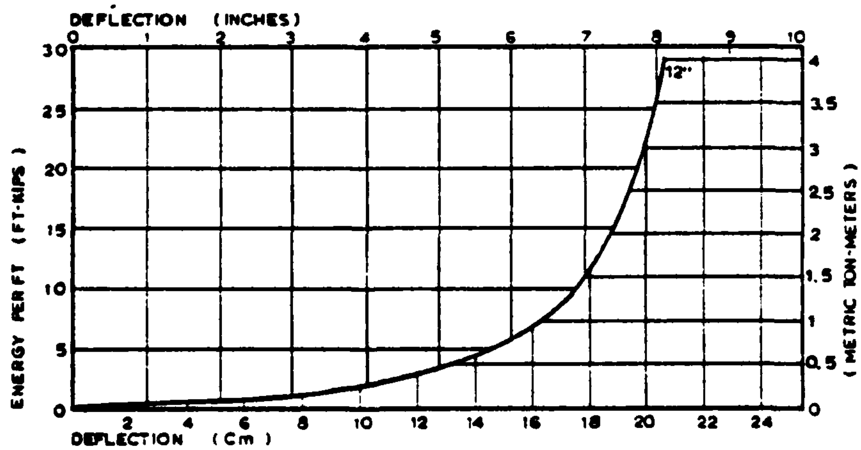
FLAT TOP WING EXTRUSION



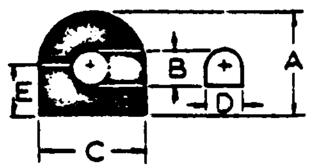
PART Nº	A	B	C	D	E	F	Wt / Ft	R / E
F7-2000	12	6	18	3	7	12	64	5.7
UNITS	INCHES						lbs	KIP/FT KIP

APPROXIMATE LOAD/ENERGY, DEFLECTION CURVES FOR MORSE STANDARD FLAT TOP WING



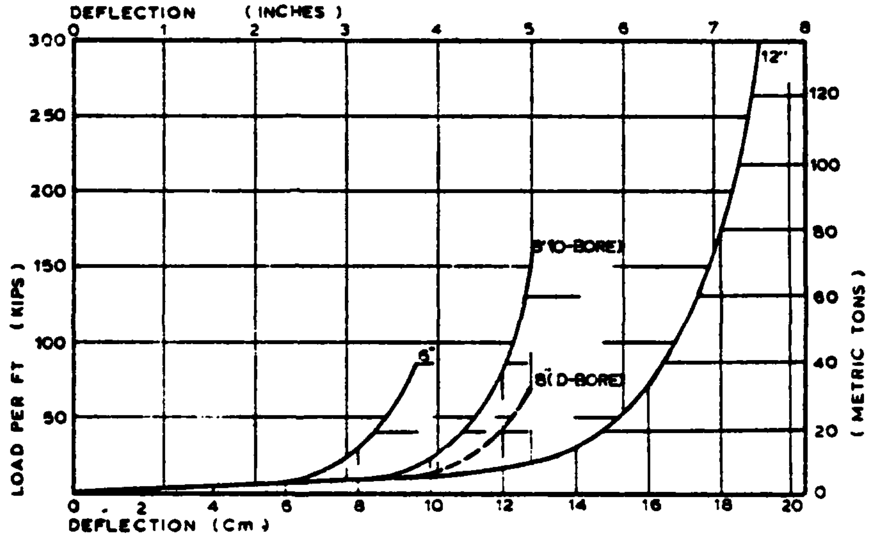


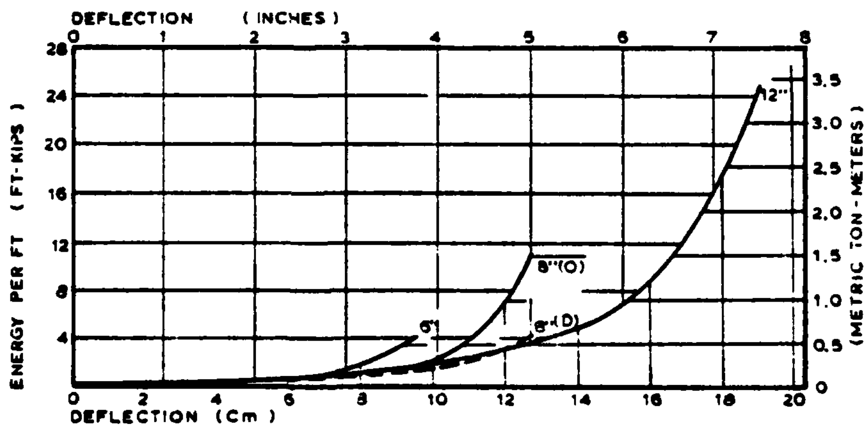
STANDARD "D" SHAPE EXTRUSION



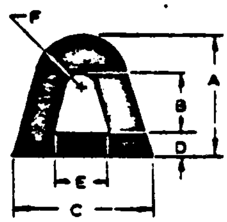
PART N°	A	B	C	D	E	Wt/Ft	R/E
F9-2000	6	2.5	5		3	11.5	15.2
F9-5000	8	3	8		4	22	10
F9-3000	12	5	12		6	54	7.7
F9-C000	8	4	8	4	4	22	10
UNITS	INCHES					lbs	[illegible]

APPROXIMATE LOAD/ENERGY, DEFLECTION CURVES FOR MORSE STANDARD "D" SHAPE



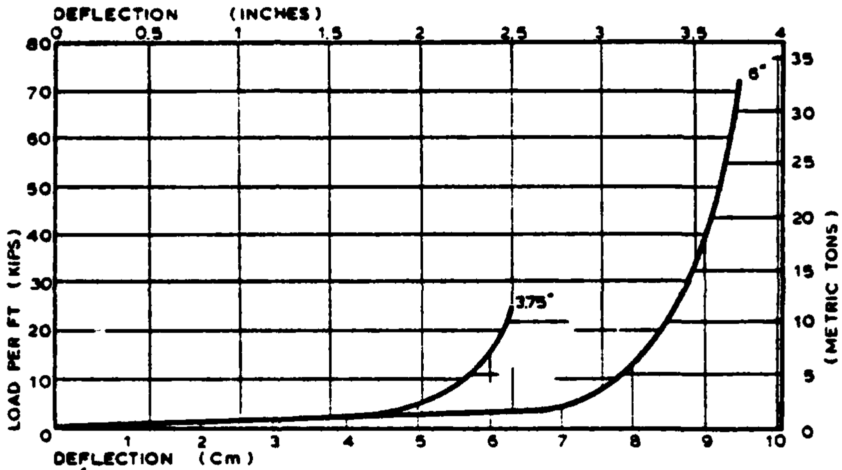


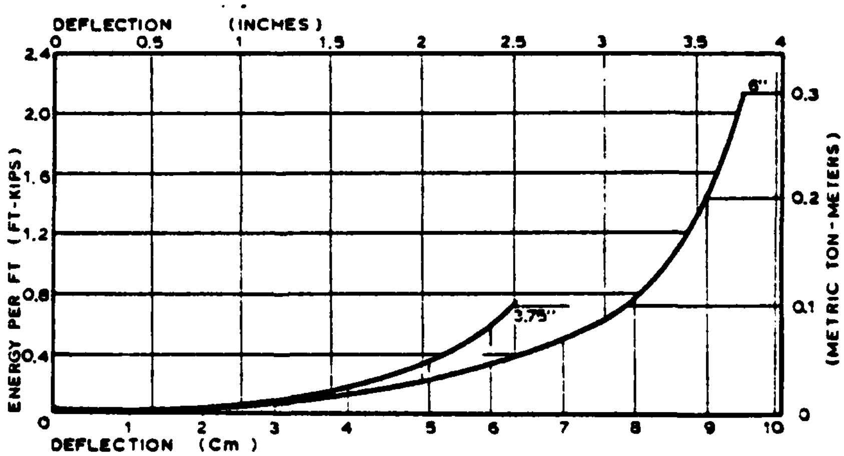
SLOPE SIDE "D" SHAPE EXTRUSION



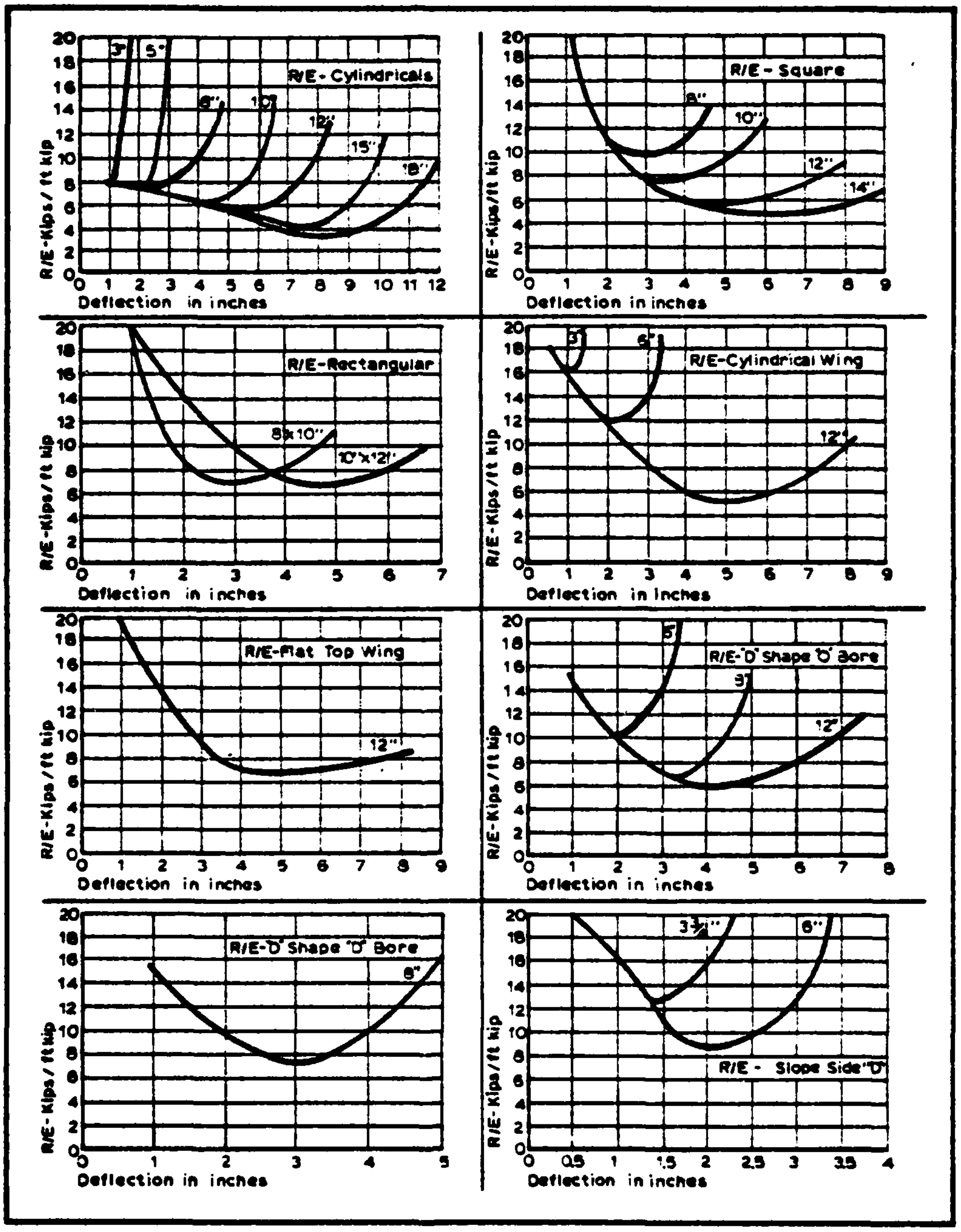
PART N°	A	B	C	D	E	F	Wt / Ft	R / E
F9-4000	3.75	2.25	4.50	.75	2	1.50	4.5	16.7
F9-1000	6	3	6.75	1.25	2.87	2.37	12.3	13.3
UNITS	INCHES						lbs	KIP/FT KIP

APPROXIMATE LOAD/ENERGY, DEFLECTION CURVES FOR MORSE STANDARD SLOPE SIDE "D" SHAPE





R/E CURVES


R/E-Cylindricals
3" 5" 6" 10" 12" 15" 18"
R/E-Kips/ft kip
Deflection in inches
R/E-Square
8" 10" 12" 14"
R/E-Kips/ft kip
Deflection in inches
R/E-Rectangular
8"x10" 10"x12"
R/E-Kips/ft kip
Deflection in inches
R/E-Cylindrical Wing
3" 6" 12"
R/E-Kips/ft kip
Deflection in inches
R/E-Flat Top Wing
12"
R/E-Kips/ft kip
Deflection in inches
R/E-'D' Shape 'O' Bore
5" 8" 12"
R/E-Kips/ft kip
Deflection in inches
R/E-'D' Shape 'D' Bore
8"
R/E-Kips/ft kip
Deflection in inches
R/E - Slope Side 'D'
3½" 6"
R/E-Kips/ft kip
Deflection in inches

PUSHNEE® AND MODULAR BUMPERS

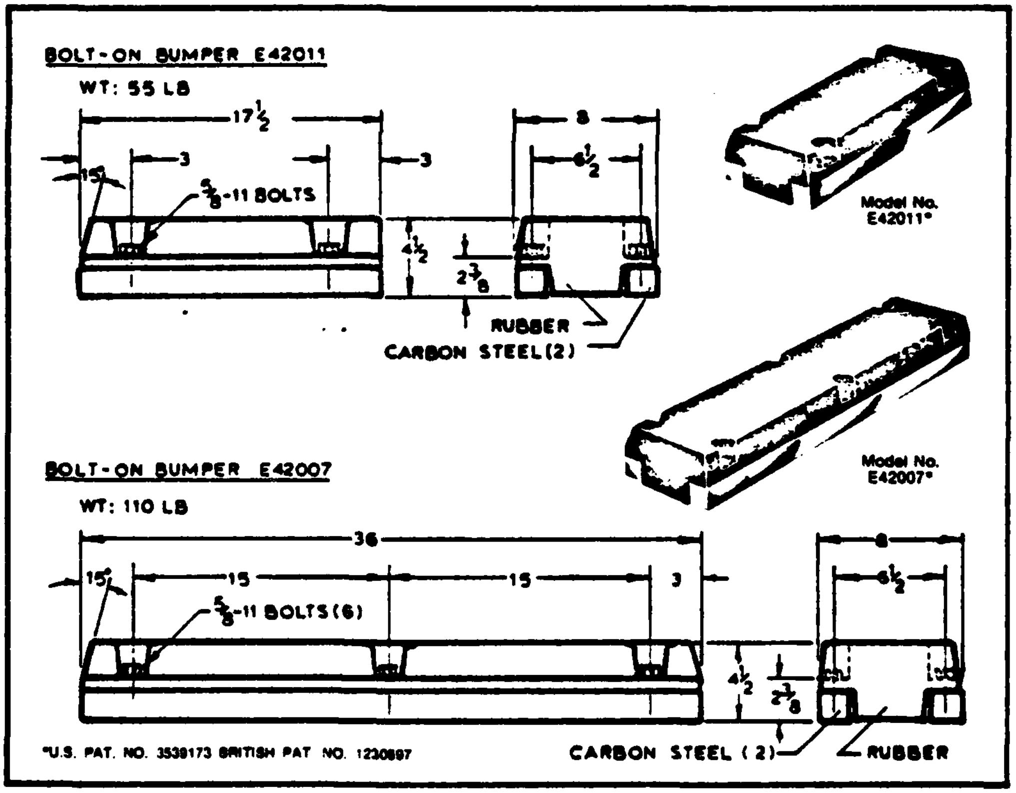
Morse offers a line of Pushnee® Bumpers that may be used individually or in combination with other fendering products. All Bumpers are made of *Neolastic®* rubber to be scuff and wear resistant. Morse Pushnee® Bumpers are also resistant to ozone, sunlight, marine growth, and temperature extremes. Bumper inserts are all carbon steel suitable for welding; however, special stocks and thicknesses are available for most Bumpers.

The patented Morse *Pushnee®* Bolt-On-Bumper comes complete with two carbon steel rails, drilled, tapped, and bolted on. Simply weld the rails in place. Then at replacement time unbolt, remove the worn Bumper, and bolt a new Bumper in place. The Bolt-On-Bumper comes in two convenient sizes. (See below).

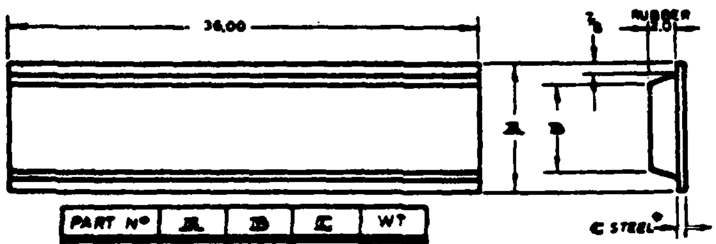
Patented Modular Weld-On-Bumpers come in two styles, flat and D-shaped. Flat Modular Bumpers are ideal protective devices that can be welded to flat or curved surfaces. The D-Shaped Modular Bumpers with either a D-bore or O-bore will absorb the same amount of energy when deflected as an Extrusion of similar size absorbs. Like the Flat Modular Bumper, the D-Shaped Modular Bumper may be welded to the flat or curved surfaces of a pile, buoy, or vessel hull. See dimensional data and typical installations on page 47.

Standard Weld-On Bumpers are available in single and double width straight units, and also in 90° arcs on a nominal 18 inch radius. Dimensional details for these Bumpers can be found on page 46.

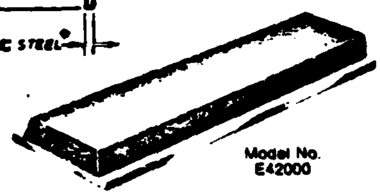
PUSHNEE® BOLT-ON BUMPERS



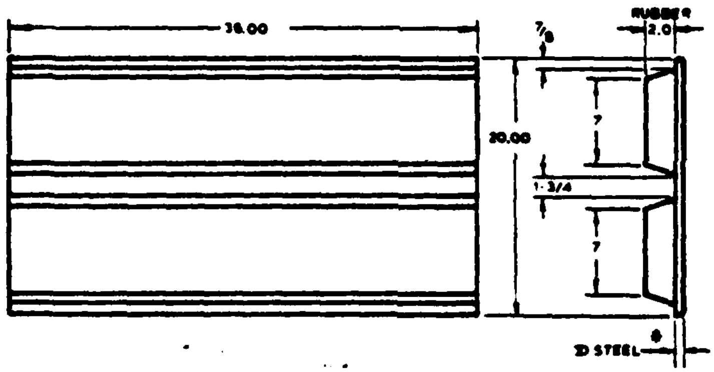
PUSHNEE* WELD-ON BUMPERS



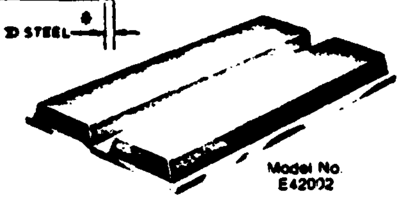
PART N°	R	D	C	WT
E42000	10	7	3/4	100LB
E42010	10	7	1/2	77LB
E42004	10	7	1/4	50LB
E42005	13-1/2	10-1/4	3/4	138LB
E42041	13-1/2	10-1/4	1/2	110LB
E42042	13-1/2	10-1/4	1/4	75LB



Model No. E42000

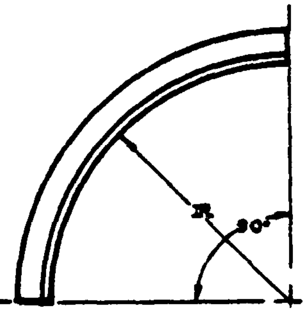


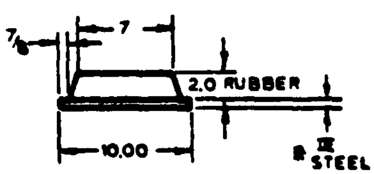
PART N°	D	WT
E42002	3/4	200LB
E42034	1/2	150LB
E42035	1/4	100LB

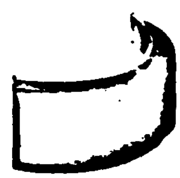


Model No. E42002

PART N°	C	R	WT
E42012	3/4	18	100LB
E42049	1/2	18-1/4	70LB
E42050	1/4	18-1/2	43LB



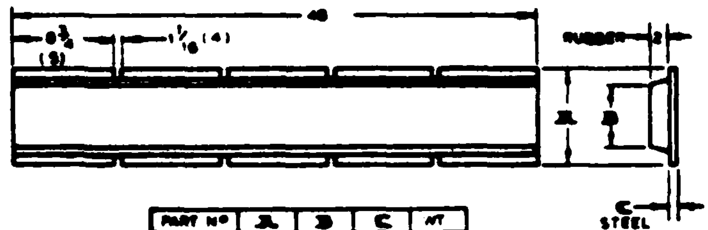


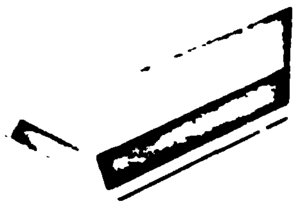


Model No. E42012

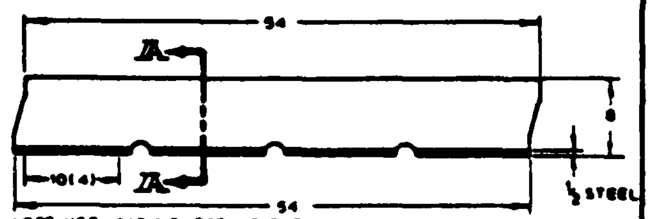
*STEEL IS STANDARD-SPECIAL PLATE STOCK & THICKNESSES AVAILABLE UPON FACTORY REQUEST

U.S. PAT. 3,084,272 MODULAR BUMPERS HEAVY-DUTY

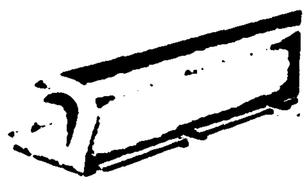




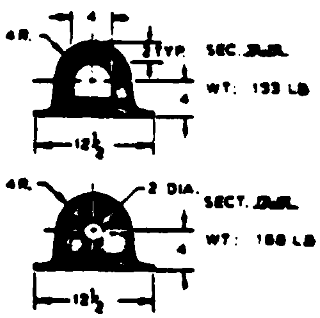
PART N°	A	B	C	WT
E47950	6	3	1/4	34LB
E47951	6	3	1/2	54LB
E47952	6	3	3/4	73LB
E47960	8	5	1/4	50LB
E47961	8	5	1/2	75LB
E47962	8	5	3/4	99LB
E47970	10	7	1/4	65LB
E47971	10	7	1/2	[illegible]
E47972	10	7	3/4	

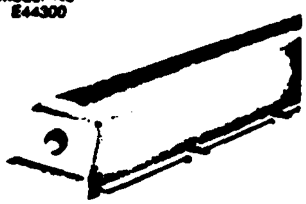


NOTE: USE LOAD & ENERGY CURVES FOR STANDARD EXTRUSIONS F9-0000 & F9-5000

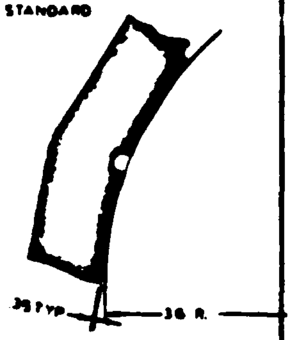


Model No. E44300

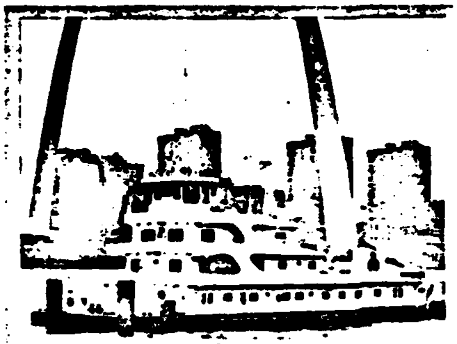




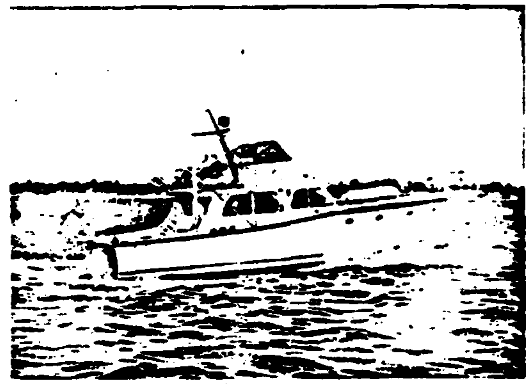
Model No. E44311



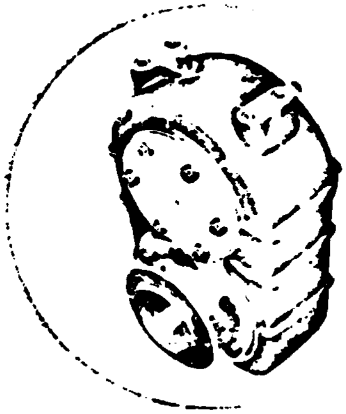
- VALUES GIVEN ON THIS SKETCH ARE CALCULATED.
- PLATES HAVE FORM (SEE SECTIONS) WHICH MAKES THEM MORE RIDGID THAN FLAT PLATES
- ONE SECTION WILL COVER APPROX. 75° ON 36" RADIUS



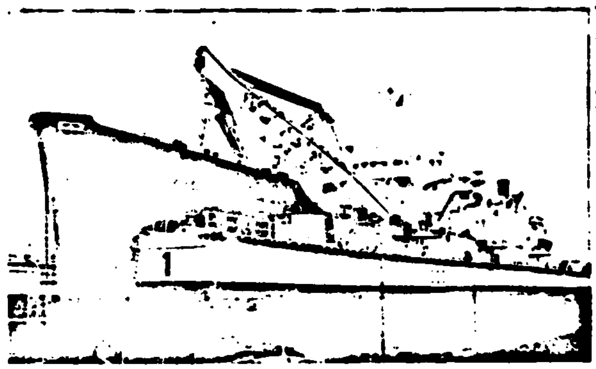
Morse Pushnee® Barge Bumpers for heavy duty usage on barges, tow boats, tugs, fishing boats — any vessel involved in heavy duty contact.



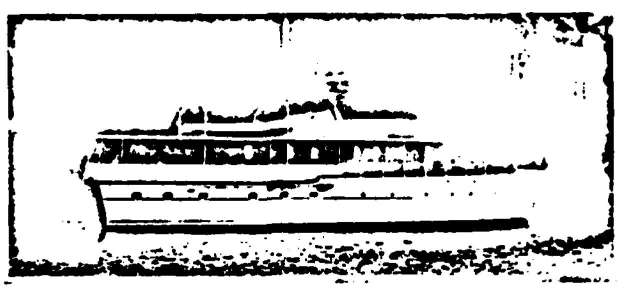
Morse Marine Bearings offer outstanding performance in pleasure crafts and seagoing vessels.



Morse Hy-Vo® Chain/case combinations are custom-designed for specific marine drive applications.

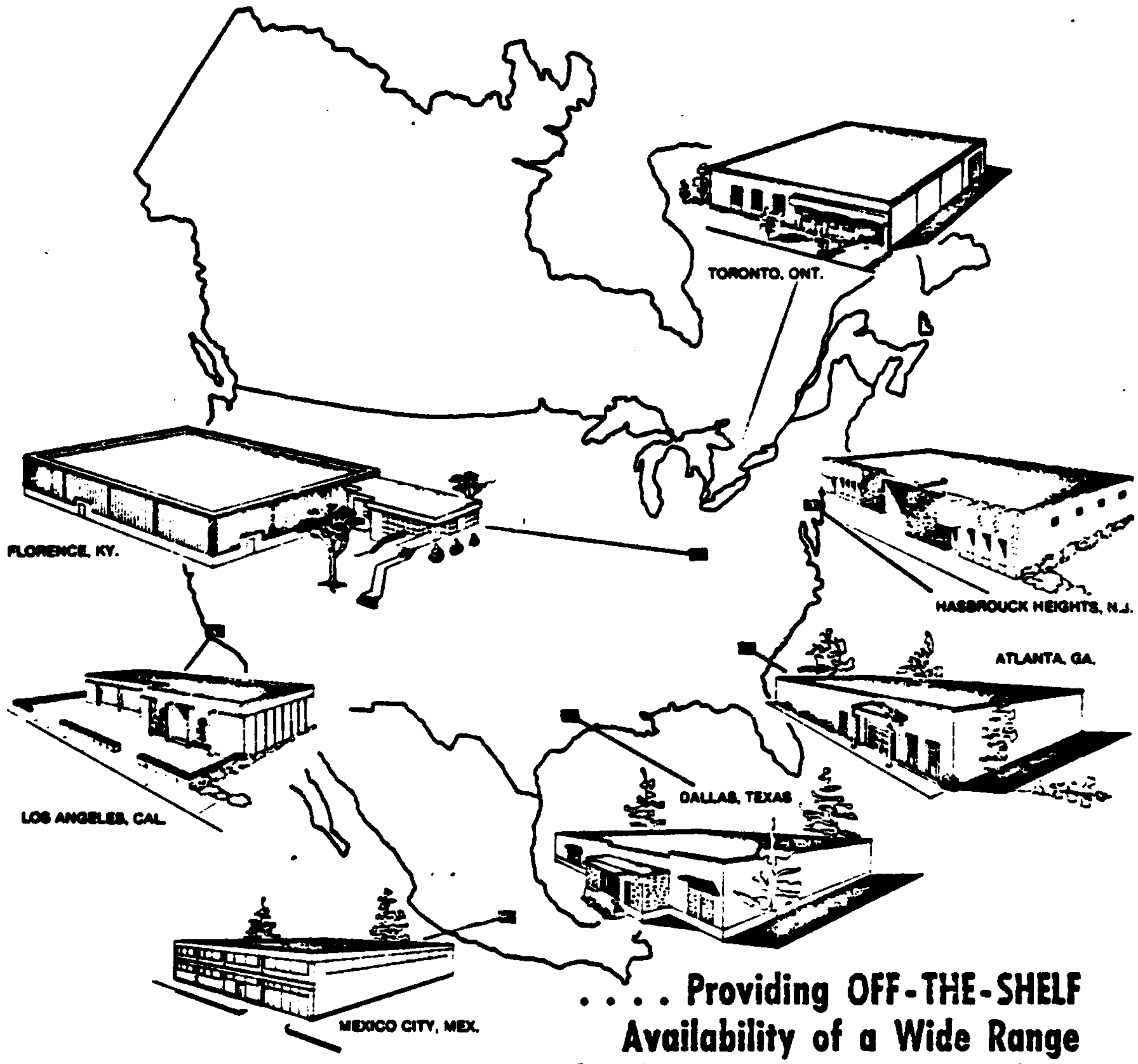


Morse Hy-Vo® powers the biggest seagoing dredge in the world.



Morse Pollution-Free Marine Bearings . . . the clean bearing that cushions the shaft . . . installs in minutes . . . and lasts for years.

MORSE® Customer Service Centers



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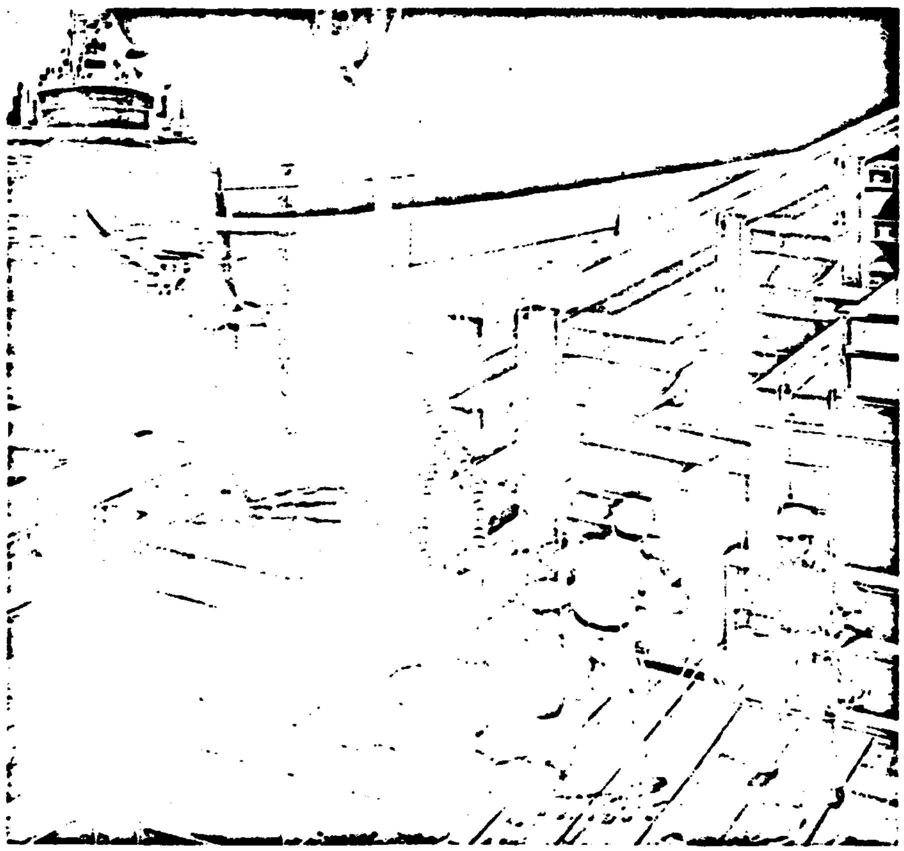
FP-80

MORSE

FENDERING PRODUCTS

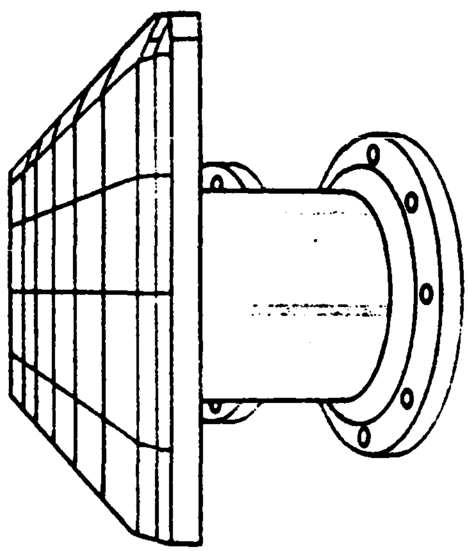


MORSE
BORG WARNER

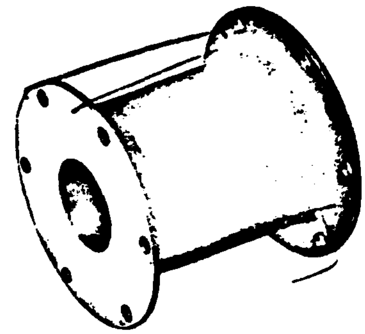
Vibration/Shock/Noise Control Products DS6101

Cell Marine Fenders

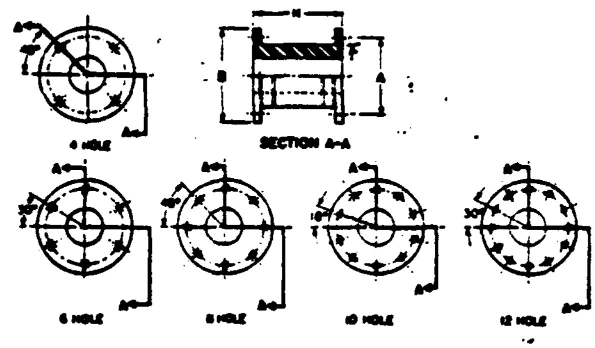
LORD Lord Kinematics



FT Series Fenders



DIMENSIONS
AND BOLT HOLE PATTERN OF FT SERIES FENDER



CHARACTERISTICS AND DIMENSIONS OF FT SERIES FENDERS

Fender Part Number	Energy Absorption ± 10% ft-kips metric ton meters — Fender Part Number -x			Reaction Load ± 10% kips metric tons — Fender Part Number -x			Rated Defl. in.	Full Defl. in.	Weight Approx. lb. kg — Fender Part No. -x	Fender Dimensions'		
	-1	-2	-3	-1	-2	-3			-1, -2, -3	H in. mm	A in. mm	B in. mm
FT0400-X	9.4	7.2	5.8	18.7	14.3	11.5	7.4	7.9	165	15.75	21.65	25.59
	1.3	1.0	0.8	8.5	6.5	5.2			75	400	550	650
FT0500-X	19.5	15.2	11.6	31.5	24.2	19.4	9.3	9.9	210	19.68	21.65	25.59
	2.7	2.1	1.6	14.3	11.0	8.8			95	500	550	650
FT0630-X	39.0	30.4	23.9	50.3	38.6	30.9	11.8	12.4	485	24.80	27.56	33.07
	5.4	4.2	3.3	22.8	17.5	14.0			220	630	700	840
FT0800-X	79.5	61.5	49.2	79.8	61.7	47.4	15.0	15.7	880	31.50	35.44	41.34
	11.0	8.5	6.8	36.2	28.0	21.5			400	800	900	1050
FT1000-X	159.8	122.9	98.3	127.7	98.1	78.5	18.7	19.7	1740	39.37	43.31	51.18
	22.1	17.0	13.6	57.9	44.5	35.6			790	1000	1100	1300
FT1150-X	243.3	187.5	150.0	163.9	128.9	103.8	21.5	22.7	2646	45.27	51.18	59.05
	34	26	21	77	59	47			1200	1150	1300	1500
FT1250-X	319.6	245.8	196.7	203.5	156.5	125.2	23.4	24.5	3310	49.21	57.09	84.96
	44	34	27	97	71	57			1500	1250	1450	1650
FT1450-X	487.9	375.0	300.5	268.3	206.4	164.9	27.2	28.5	5070	57.08	64.96	72.83
	67	52	42	122	94	75			2300	1450	1650	1850
FT1600-X	639.1	491.6	393.3	319.7	245.9	196.7	29.9	31.5	6615	63.00	70.87	78.74
	88	68	54	145	112	89			3000	1600	1800	2000
FT1700-X	789.2	604.5	486.1	368.2	282.2	227.1	31.8	33.6	8160	66.93	74.80	82.67
	109	84	67	167	128	103			3700	1700	1900	2100
FT2000-x	1278.3	983.3	786.6	508.9	391.4	313.1	37.4	39.4	11025	78.74	78.74	66.62
	177	136	109	231	178	142			5000	2000	2000	2200
FT2250-X	2063.4	1556.6	1303.2	716.6	551.2	463.0	42.0	44.5	16320	88.58	90.55	100.39
	286	215	180	325	250	210			7400	2250	2300	2550
FT2500-X	2823.6	2135.8	1810.0	893.0	672.5	573.3	46.8	49.2	23600	98.42	106.30	116.14
	390	295	250	405	305	260			10700	2500	2700	2950
FT3000-X	4860.0	3692.0	3113.0	1279.0	970.0	827.0	56.1	59.0	40800	118.12	127.96	137.80
	670	510	430	580	440	375			18600	3000	3250	3500

SPECIFICATION

Material—Flexing Element—Natural Rubber Blend
Metal Plates—ASTM A283-70A, Grade C or equivalent.

For specific details and dimensions, please call or write the main plant listed on the back page.

PERFORMANCE CURVES

Curves shown are typical for the Cell Fenders. Specific curves for individual fenders will be provided upon request.

PERFORMANCE THEORY

The annular column design of the Cell Fender combines two engineering principles to produce exceptional energy absorbing capacity with low reaction force. First, the buckling column effect enables the fender to absorb initial impact in compression. Second, when buckling occurs the fender continues to absorb energy as it deflects, however, without an increase in reaction force. Third, added to the buckling column effect is the hoop effect, which gives added strength and energy capability.

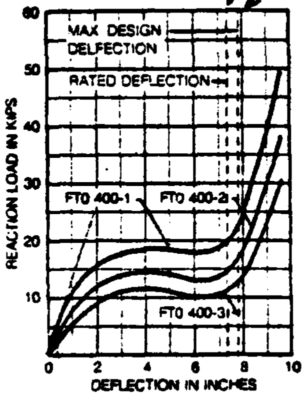
SYSTEM PERFORMANCE

Frontal frames and hardware designed and manufactured by Lord Kinematics combine with Cell Fenders to complete the system. Low hull pressure is achieved through properly sized contact area. Low shear forces are the result of low coefficient of friction polymeric contact pads which are resistant to wear, gouging, and tearing.

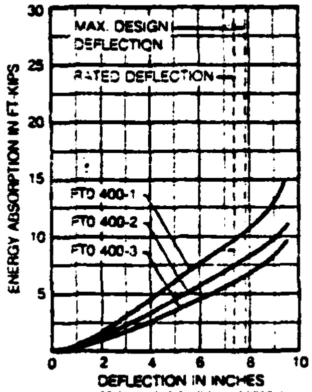
SYSTEM ECONOMY

Complete Cell Fender Systems are economical to purchase and install. Their performance permits new installations to be designed to cost less and existing installations to handle large vessels. Generally, the frontal frame requires no pile support which also reduces cost.

FT0400 Fender

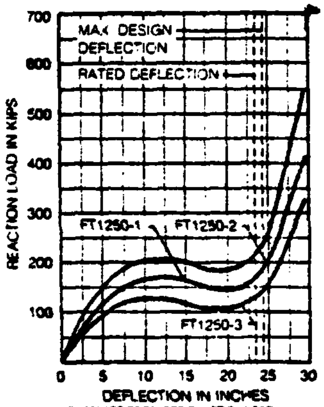


FT0400 SERIES FENDER REACTION LOAD-DEFLECTION CURVES (C-535[illegible])

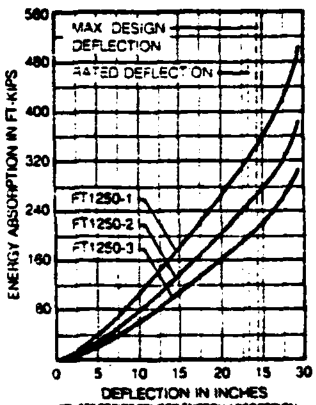


FT0400 SERIES FENDER ENERGY ABSORPTION-DEFLECTION CURVES (C-535[illegible])

FT1250 Fender

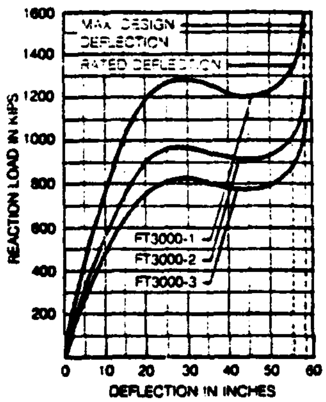


FT1250 SERIES FENDER REACTION LOAD-DEFLECTION CURVES (C-53594)

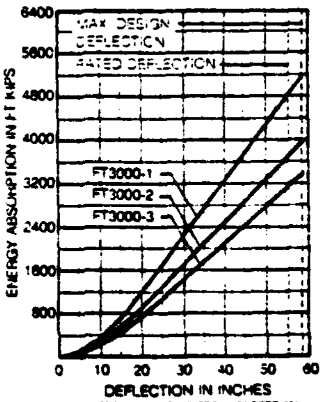


FT1250 SERIES FENDER ENERGY ABSORPTION-DEFLECTION CURVES (C-53594)

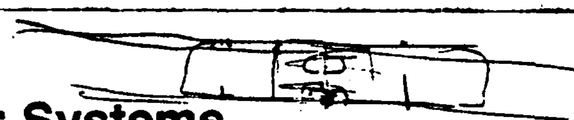
FT3000 Fender



FT3000 SERIES FENDER REACTION LOAD-DEFLECTION CURVES (C-53601)



FT3000 SERIES FENDER ENERGY ABSORPTION-DEFLECTION CURVES (C-53601)



Cell Marine Fender Systems

Cell Fenders are available in the range of sizes listed on page 2. They can be designed into new or existing berthing facilities in a variety of patterns. Figure 1 shows some of the typical arrangements that are recommended.

A typical Cell Fender and frame installation as shown in Figures 2 and 3 includes anchor bolts, lateral restraint and weight support chains as part of the system. Qualified engineers at Lord Kinematics can help you develop the additional fender system details pertaining to installation dimensions and system component materials.

FIGURE 1

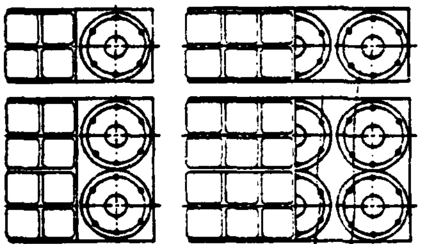
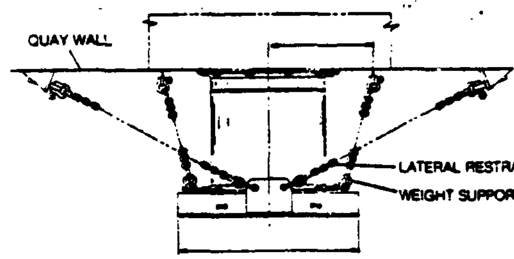


FIGURE 2 TOP VIEW



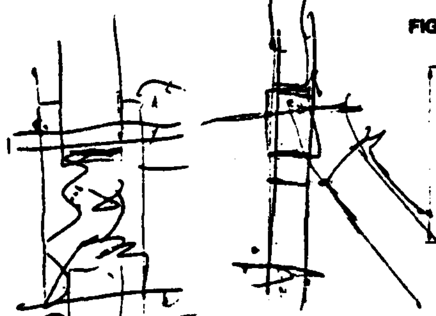
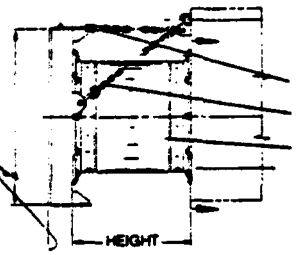


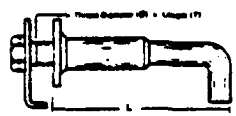
FIGURE 3 SIDE VIEW



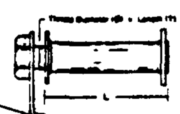
Fender Anchors

Specially designed anchor sleeves, bolts and washers for embedment during concrete casting are available for each fender. Each kit includes sleeve, bolt and washer.

J-13945 SERIES



J-14445 SERIES



Anchor Sleeve Part Number	Use with Fender Part Number	Number Required Each Fender	Imbedded Length (L) in inches	Bolt Thread 0 x T in inches
J-13945-1	FT0400	4	7-3/8	7/8 x 2-1/2
J-13945-2	FT0500	4	7-7/8	1 x 2-1/2
J-14445-1	FT0630	4	7-1/8	1-1/8 x 3-1/4
J-14445-2	FT0800	6	8-1/2	1-1/4 x 4
J-14445-3	FT1000	6	10-3/4	1-1/2 x 4-3/4
J-14445-15	FT1150	6	12-1/2	1-5/8 x 5-1/8
J-14445-4	FT1250	6	13-1/2	1-3/4 x 5-1/2
J-14445-16	FT1450	6	15-1/2	2 x 6-1/2
J-14445-5	FT1600	8	15-1/2	2 x 6-3/8
J-14445-17	FT1700	8	15-3/4	2-1/4 x 6-3/4
J-14445-6	FT2000	8	16	2-1/2 x 7-3/4
J-14445-18	FT2250	10	16-3/4	2-1/2 x 7-3/4
J-14445-19	FT2500	10	16-3/8	2-1/2 x 7-3/4
J-14445-14	FT3000	12	20	3 x 7-1/2

For More Information:

Lord Kinematics
Lord Corporation
1635 West 12th Street
P.O. Box 2051
Erie, PA 16512
(814) 456-8511 Main

868 7691 Young
868-3611

LORD Lord Kinematics

APPENDIX B

CURRENT LOADS

Current Variations Considered	1-3 knots
Current Maximum Considered	7 knots
Immersion Depth Maximum	20 feet
Piling Diameters Considered	6 inches
	12 inches
	18 inches

Reynold's Number Calculated for each Diameter and velocity

$$Re = \frac{U_\infty D_p}{\nu}$$

Drag Coefficient obtainef from Reference 5, P. 17

Calculation of Drag Force F_d using

$$F_D = C_D A \frac{\rho U_\infty^2}{2} \quad \text{[Ref. 4, P. 223]}$$

	1 knot	2 knots	3 knots	7 knots
6"	32.65 lbf	54.41 lbf	127.32 lbf	799.84 lbf
12"	65.27 lbf	74.064 lbf	185.05 lbf	1756.32 lbf
18"	82.65 lbf	119.1 lbf	297.50 lbf	2793.1 lbf

APPENDIX C

WIND LOADS

Wind Variations Considered	0-75 miles/hour
Wind Maximum Considered	75 miles/hour
Piling Exposed to Wind	12 feet
Sail Area Exposed to Wind	9 sq. feet
Piling Diameters Considered	6 inches
	12 inches
	18 inches

Reynold's Number Calculated for each Diameter and Velocity

$$Re = \frac{U_\infty D_p}{\nu}$$

Drag Coefficient for piling taken from Reference 5, P. 17

Drag Coefficient for sail area taken from Reference 4, P. 388

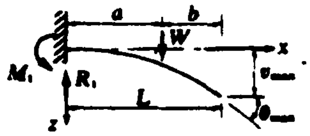
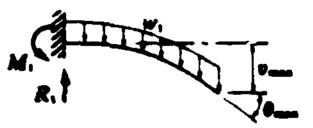
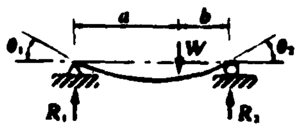
Calculation of Drag Force F_d using

$$F_D = D_C A \frac{\rho U_\infty^2}{2} \quad \text{[Ref. 4, P. 223]}$$

	20	40	60	75
sail area	10.94 lbf	44.16 lbf	99.21 lbf	155.27 lbf
6" piling	3.65 lbf	14.7 lbf	33.05 lbf	51.64 lbf
12" piling	7.26 lbf	29.32 lbf	65.86 lbf	102.91 lbf
18" piling	10.94 lbf	44.16 lbf	99.21 lbf	155.02 lbf

APPENDIX D

BEAM EQUATIONS

Type of Beam	Reactions	Deflection at Any Point x
	$R_1 = W$ $M_1 = Wa$	For $x < a$, $\frac{W}{6EI}(-x^3+3x^2a)$ For $x \geq a$ $\frac{W}{6EI}(3a^2x-a^3)$
	$R_1 = w_1L$ $M_1 = \frac{w_1L^2}{2}$	$\frac{w_1x^2}{24EI}(x^2+6L^2-4Lx)$
	$R_1 = 0$ $M_1 = M^*$	$\frac{M^*x^2}{2EI}$
	$R_1 = \frac{Wb}{L}$ $R_2 = \frac{Wa}{L}$	For $x < a$, $\frac{Wb}{6LEI}[-x^3+(L^2-b^2)x]$ For $x \geq a$, $\frac{Wb}{6LEI}\left[\frac{L}{b}(x-a)^3-x^3+(L^2-b^2)x\right]$

Maximum Deflection	Important Slopes	Maximum Moment	Maximum Shear Force
$\frac{Wa^2(3L-a)}{6EI}$	$\theta_{max} = \frac{Wa^2}{2EI}$	Wa at $x = 0$	W at $x < a$
$\frac{w_1 L^4}{8EI}$	$\theta_{max} = \frac{w_1 L^3}{6EI}$	$\frac{w_1 L^2}{2}$ at $x = 0$	$w_1 L$ at $x = 0$
$\frac{M^* L^2}{2EI}$	$\theta_{max} = \frac{M^* L}{EI}$	M^* at all x	0
$\frac{Wb(L^2-b^2)^{3/2}}{9\sqrt{3}\, LEI}$ at $x = \sqrt{(L^2-b^2)/3}$	$\theta_1 = \frac{Wab(2L-a)}{6LEI}$ $\theta_2 = \frac{Wab(2L-b)}{6LEI}$	$\frac{Wab}{L}$ at $x = a$	If $a > b$, $W\frac{a}{L}$ at $x > a$ If $a < b$, $W\frac{b}{L}$ at $x < a$

APPENDIX E

GIFTS

The GIFTS system is a finite element linear analysis program presently available for use at the Naval Postgraduate School, Monterey, California.

GIFTS may be used to construct finite element models, display created models, add loads and define boundary conditions, and perform static or dynamic analysis. These capabilities are fully explained through the use of GIFTS' documentation library available through Prof. G. Cantin, Mechanical Engineering Department, at the Naval Postgraduate School.

For the purpose of this thesis the EDITM module was used to create a 6 element, 3 dimensional, circular cross section beam element.

A typical program running sequence includes;

EDITM	model generation
EDITLB	load and boundary condition definitions
OPTIM	optimizes the internal numbering sequence in order to reduce disk requirements and increase the speed of solution
STIFF	creates the stiffness matrix
DECOM	decomposes stiffness matrix
DEFL	calculates deflections
STRESS	calculates stress

RESULT allows user to review solution

Included in this appendix is a typical collection of ouput data from the GIFTS program.

```
JOB MILLER          9- 8-82      LOADING CASE  1         9.58.44      PAGE  1
                                       LOADS
NP         VX           VY           VZ           MX           MY           MZ
   6   0            0.          -3.000E+02  0.          0.           0.

*
```

JOB MILLER 9- 8-82 9:55:12 PAGE 1

NP	X	Y	Z	DEP	MFP	LPD
1	0.0	0.0	0.0	0	111111	000000
2	1.2000E+00	0.0	0.0	0	111111	000000
3	2.4000E+00	0.0	0.0	0	111111	000000
4	3.6000E+00	0.0	0.0	0	111111	000000
5	4.8000E+00	0.0	0.0	0	111111	000000
6	6.0000E+00	0.0	0.0	0	111111	000000
7	5.0000E-01	0.0	-1.0000E+01	0	111111	000000
8	1.5000E+00	0.0	-1.0000E+01	0	111111	000000
9	2.8333E+00	0.0	-1.0000E+01	0	111111	000000
10	4.1667E+00	0.0	-1.0000E+01	0	111111	000000
11	5.5000E+00	0.0	-1.0000E+01	0	111111	000000

*

```
JOB MILLER                 9- 8-82                9 53:28               PAGE  1
NM TYP      E            V             G            SY            P             A
 1   1   1 200E+03   4 800E-01   4 054E+02   5 000E+02   7 339E-04   6 500E-06

 *
```

```
JOB MILLER                9- 8-82              9 52  1           PAGE  1

THICKNESS GROUP ¤ 1 --- HOLLOW CIRCULAR
 RO - 3 0000E+00           ZA - 0 0
 RI - 2 5000E+00           YA - 0 0
                           TH - 0 0

 *
```

JOB MILLER 9- 8-82 LOADING CASE 1 10:17:10 PAGE 1

NP	U	V	W	THX	THY	THZ
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	-1.181E-01	0.0	2.459E-02	0.0
3	0.0	0.0	-2.624E-01	0.0	4.372E-02	0.0
4	0.0	0.0	-4.264E-01	0.0	5.738E-02	0.0
5	0.0	0.0	-6.035E-01	0.0	6.558E-02	0.0
6	0.0	0.0	-7.872E-01	0.0	6.831E-02	0.0

*

APPLIED LOADS

QX 0.0

QY 0.0

QZ 0.0

QMX 0.0

ELEMENT NO 1
LOADING CASE 1

LIST DESIRED X/L VALUES

?
1

RESULTANT FORCES

N 0.0

UY 0.0

UZ 1.500E+02

MX 0.0

BY -9.000E+02

BZ 0.0

BEAM PROPERTIES

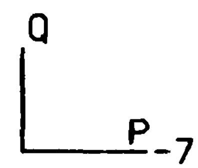
A = 8.639E+00
AQ= 4.320E+00
AP= 4.320E+00
IP= 3.294E+01
IQ= 3.294E+01
J = 6.588E+01
ZG= 0.0
YG= 0.0
ZO= 0.0
YO= 0.0
AL= 0.0

YIELD STRESS

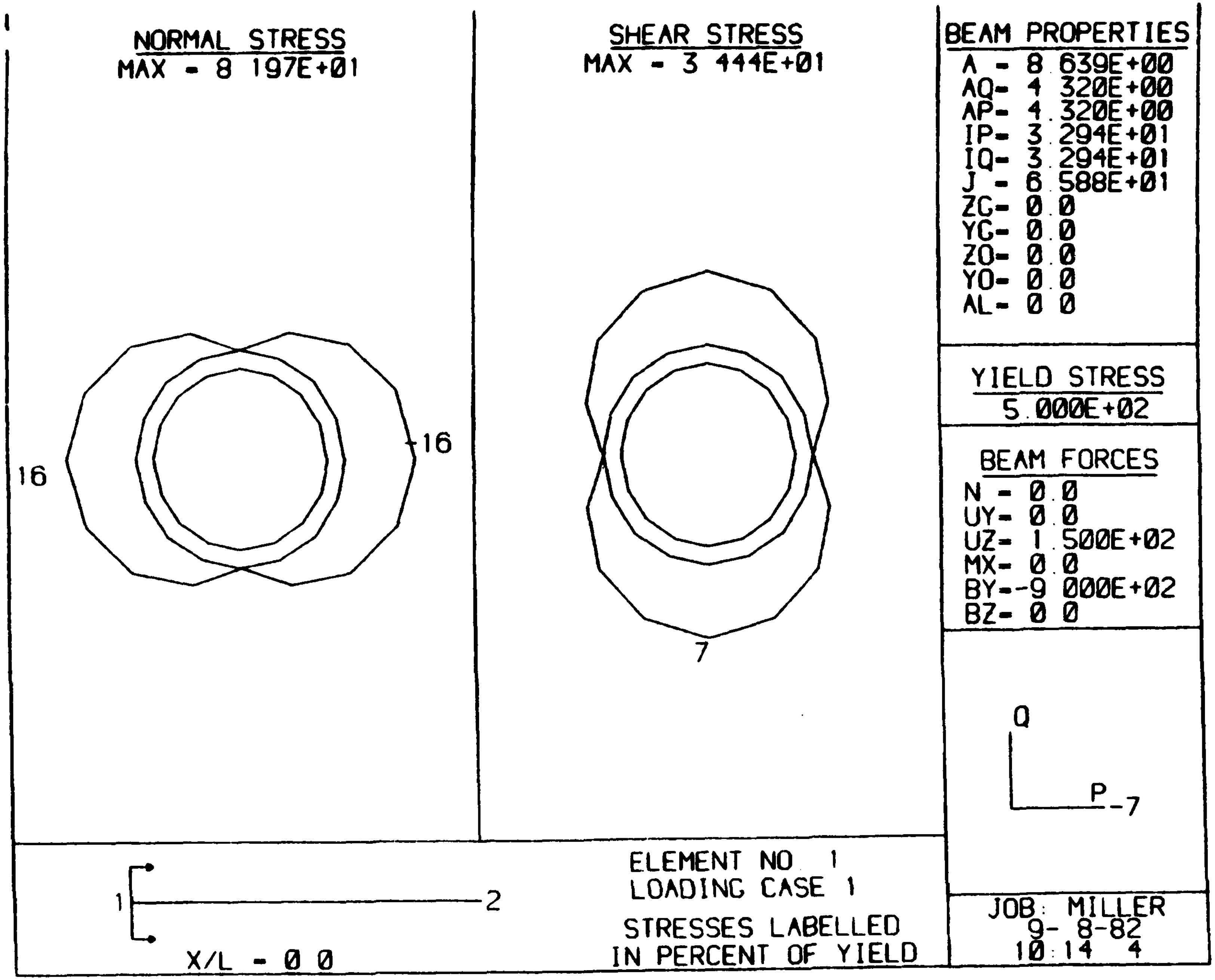
5.000E+02

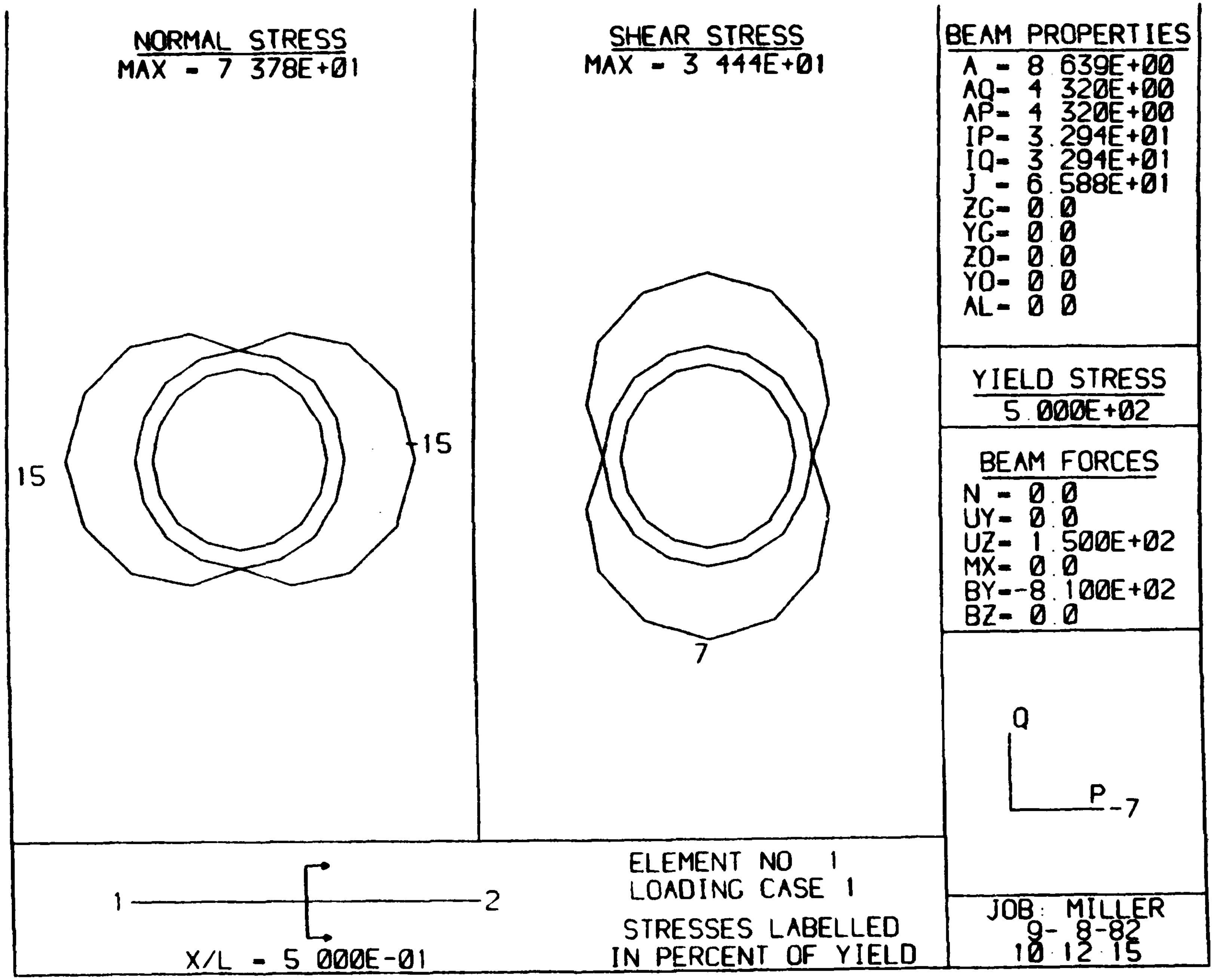
BEAM FORCES

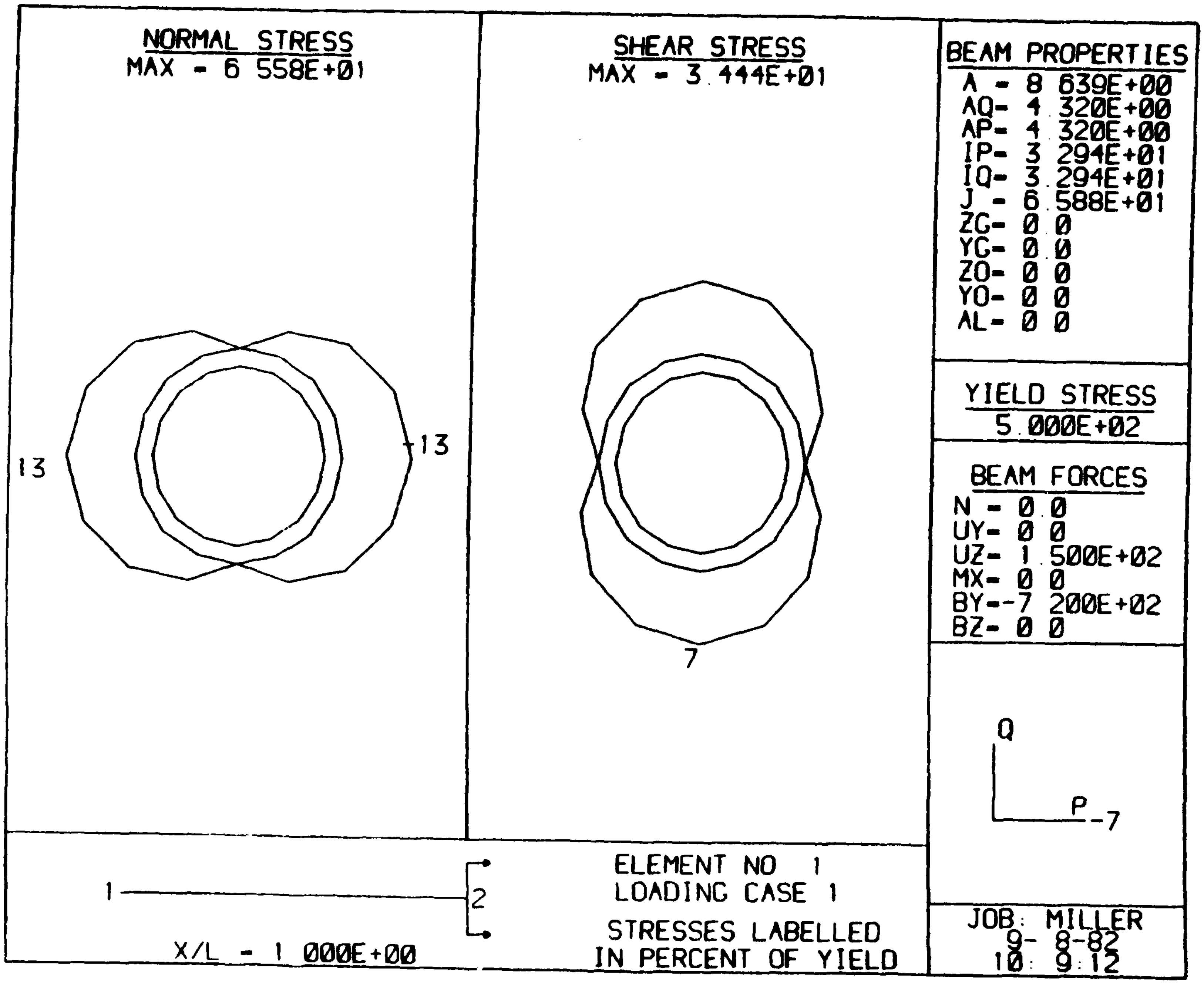
N = 0.0
UY= 0.0
UZ= 1.500E+02
MX= 0.0
BY=-8.100E+02
BZ= 0.0



JOB. MILLER
9- 8-82
10: 9:57


NORMAL STRESS
MAX - 8 197E+01
16
-16
SHEAR STRESS
MAX - 3 444E+01
7
BEAM PROPERTIES
A - 8 639E+00
AQ- 4 320E+00
AP- 4 320E+00
IP- 3 294E+01
IQ- 3 294E+01
J - 6 588E+01
ZC- 0 0
YC- 0 0
ZO- 0 0
YO- 0 0
AL- 0 0
YIELD STRESS
5 000E+02
BEAM FORCES
N - 0 0
UY- 0 0
UZ- 1 500E+02
MX- 0 0
BY- -9 000E+02
BZ- 0 0
Q
P
-7
1
2
X/L - 0 0
ELEMENT NO 1
LOADING CASE 1
STRESSES LABELLED
IN PERCENT OF YIELD
JOB: MILLER
9- 8-82
10:14 4


NORMAL STRESS
MAX - 7 378E+01
15
15
SHEAR STRESS
MAX - 3 444E+01
7
BEAM PROPERTIES
A - 8 639E+00
AQ- 4 320E+00
AP- 4 320E+00
IP- 3 294E+01
IQ- 3 294E+01
J - 6 588E+01
ZG- 0 0
YG- 0 0
ZO- 0 0
YO- 0 0
AL- 0 0
YIELD STRESS
5 000E+02
BEAM FORCES
N - 0 0
UY- 0 0
UZ- 1 500E+02
MX- 0 0
BY--8 100E+02
BZ- 0 0
Q
P
-7
1
2
X/L - 5 000E-01
ELEMENT NO 1
LOADING CASE 1
STRESSES LABELLED
IN PERCENT OF YIELD
JOB: MILLER
9- 8-82
10 12 15


NORMAL STRESS
MAX - 6 558E+01
13
+13
SHEAR STRESS
MAX - 3 444E+01
7
BEAM PROPERTIES
A - 8 639E+00
AQ- 4 320E+00
AP- 4 320E+00
IP- 3 294E+01
IQ- 3 294E+01
J - 6 588E+01
ZG- 0 0
YG- 0 0
ZO- 0 0
YO- 0 0
AL- 0 0
YIELD STRESS
5 000E+02
BEAM FORCES
N - 0 0
UY- 0 0
UZ- 1 500E+02
MX- 0 0
BY--7 200E+02
BZ- 0 0
Q
P
-7
1
2
X/L - 1 000E+00
ELEMENT NO 1
LOADING CASE 1
STRESSES LABELLED
IN PERCENT OF YIELD
JOB: MILLER
9- 8-82
10: 9:12

APPENDIX F

ADINA

ADINA is a flexible finite element program allowing linear and nonlinear, static and dynamic analysis. The program offers a choice of six element types and twenty material models that are used in conjunction with the different elements types. For the purpose of this thesis a 3-dimensional circular cross section beam element was employed. Ideally this element should have been coupled with Mooney-Rivilin material model. However in ADINA this material type is only availble in 2-dimensional continuum elements for plane stress only. It was decided to use the elastic-plastic material model even though it did not match the response of the linear through nonlinear ranges. Using ADINA's nonlinear formulation to allow for large displacement, it was hoped that the elastic-plastic material model's response would map any slight linear response exhibited by the experimental model. Included in this appendix is a typical ADINA output and associated data file.

Although the version of ADINA installed at the Naval Postgraduate School is not the most current, it is an extremely powerful tool. Additional information on the many applications of ADINA may be received from Prof. G. Cantin, Mechanical Engineering Department, at the Naval Postgraduate School.

```
FILE: ADINA     OUTPUT   A   NAVAL POSTGRADUATE SCHOOL                                                PAGE 001

    STATIC ANALYSIS OF A CIRCULAR CROSS-SECTION RUBBER BEAM
    3CCCCC00    C    1    1    2         0.1         0.0    0    0    0    00
    C   0       C    C
    0   1       C   .50        0
        1          0.C
    C   1       C    C

    1   1       1    1    1    1    1        0.0          0.0         0.0    0
    1   0       1    1    1    1    0    1.900            0.0         0.0    0
    3   1       1    1    1    1    1    1.900        -10.0           0.0    0
    2   2       2    0
    C   0
   4    1   1   0    1                   5    5    5        0    0    2    1    1
    1   2       C          1.0
    12CC 1          .48        3.800          2.5      1200.         0.0
    1   1       2    3         1    1    0          0
    1   2
        C.C         C.735       1.0       0.735
    2   2
        C.0      1C6.660        1.0     106.660
    2   2       1                            0.0
    3   6       2                            0.0
    C
1
```

```
************************************************************************
**                                                                    **
**                    A FINITE ELEMENT PROGRAM FOR                    **
**          AUTOMATIC DYNAMIC INCREMENTAL NONLINEAR ANALYSIS          **
**                                                                    **
**    AAAAAAAAA    DDDDDDDDD    IIIIIIIIIII   NN       NN   AAAAAAAAA    **
**   AAAAAAAAAAA   DDDDDDDDDD   IIIIIIIIIII   NNN      NN  AAAAAAAAAAA   **
**   AA       AA   DD       DD      II        NNNN     NN  AA       AA   **
**   AA       AA   DD       DD      II        NN NN    NN  AA       AA   **
**   AA       AA   DD       DD      II        NN  NN   NN  AA       AA   **
**   AAAAAAAAAAA   DD       DD      II        NN   NN  NN  AAAAAAAAAAA   **
**   AAAAAAAAAAA   DD       DD      II        NN    NN NN  AAAAAAAAAAA   **
**   AA       AA   DD       DD      II        NN     NNNN  AA       AA   **
**   AA       AA   DD       DD      II        NN      NNN  AA       AA   **
**   AA       AA   DDDDDDDDDD   IIIIIIIIIII   NN       NN  AA       AA   **
**   AA       AA   DDDDDDDDD    IIIIIIIIIII   NN        N  AA       AA   **
**                                                                    **
**  REFERENCE- REPORT 82448-1, ACOUSTICS AND VIBRATION LABORATORY,    **
**             M. I. T., 1975 ( REV.-MAY 1976 )                       **
**                                                                    **
************************************************************************

1    STATIC ANALYSIS OF A CIRCULAR CROSS-SECTION RUBBER BEAM
```

```
M A S T E R   C O N T R O L   C A R D S

CARD NUMBER 1
    NUMBER OF NODAL POINTS . . . . . . . . . . . (NUMNP)   =    3
    MASTER X-TRANSLATION CODE . . . . . . . . . (IDOF(1)) =    0
    MASTER Y-TRANSLATION CODE . . . . . . . . . (IDOF(2)) =    0
    MASTER Z-TRANSLATION CODE . . . . . . . . . (IDOF(3)) =    0
    MASTER X-ROTATION    CODE . . . . . . . . . (IDOF(4)) =    0
    MASTER Y-ROTATION    CODE . . . . . . . . . (IDOF(5)) =    0
    MASTER Z-ROTATION    CODE . . . . . . . . . (IDOF(6)) =    0
    NUMBER OF LINEAR ELEMENT GROUPS . . . . . . (NEGL)    =    0
    NUMBER OF NONLINEAR ELEMENT GROUPS . . . . (NEGNL)   =    1
    SOLUTION MODE . . . . . . . . . . . . . . . (MODEX)   =    1
       EQ.0, DATA CHECK
       EQ.1, EXECUTION
       EQ.2, RESTART
    NUMBER OF TIME STEPS . . . . . . . . . . . (NSTE)    =    2
    TIME STEP INCREMENT . . . . . . . . . . . . (DT)    = 0.1000D+00
    TIME AT SOLUTION START . . . . . . . . . . (TSTART)= 0.0
    PRINTING INTERVAL . . . . . . . . . . . . . (IPRI)    =    1
    RESTART SAVE INTERVAL . . . . . . . . . . . (IRINT)   = 9999
    TEMPERATURE TAPE FLAG . . . . . . . . . . . (ITP96)   =    0
       EQ.0, TEMPERATURE TAPE NOT USED,
       EQ.1, TEMPERATURE TAPE USED


CARD NUMBER 2
    MASS MATRIX CODE . . . . . . . . . . . . . (IMASS)   =    0
       EQ.0, NO MASS EFFECTS
       EQ.1, LUMPED MASS
       EQ.2, CONSISTENT MASS
    DAMPING MATRIX CODE . . . . . . . . . . . . (IDAMP)   =    0
       EQ.0, NO DAMPING
       EQ.1, DAMPING INCLUDED
    NUMBER OF NODAL MASSES . . . . . . . . . . (IMASSN)  =    0
    NUMBER OF NODAL DAMPERS . . . . . . . . . . (IDAMPN)  =    0

CARD NUMBER 3
    FREQUENCIES SOLUTION CODE . . . . . . . . . (IEIG)    =    0
       EQ.0, NO FREQUENCIES SOLUTION
       EQ.1, FREQUENCIES AND MODE SHAPES
             ARE DETERMINED
```

```
CARD NUMBER 4
    NUMBER OF TIME STEPS BETWEEN REFORMING
      EFFECTIVE STIFFNESS MATRIX . . . . . . . . (ISREF)   =     1
    NUMBER OF ALLOWABLE STIFFNESS REFORMATIONS
      IN EACH TIME STEP . . . . . . . . . . . . (NUMREF)   =     0
    NUMBER OF TIME STEPS BETWEEN
      EQUILIBRIUM ITERATIONS  . . . . . . . . . (IEQUIT)   =     1
    MAXIMUM NUMBER OF EQUILIBRIUM
      ITERATIONS PERMITTED  . . . . . . . . . . (ITEMAX)   =    50
    CONVERGENCE TOLERANCE . . . . . . . . . . . (RTOL)= 0.100-02

CARD NUMBER 5
    TIME INTEGRATION CODE . . . . . . . . . . . (IOPE)     =     1
       EQ.1, WILSONS THETA METHOD
       EQ.2, NEWMARKS METHOD
    INTEGRATION PARAMETER . . . . . . . . . . . (THETA)    =   0.0

CARD NUMBER 6
    NUMBER OF BLOCKS OF NODAL PRINTOUT  . . . . . . (NPB)  =     1
    DISPLACEMENT PRINTOUT CODE  . . . . . . . . . . (IDC)  =     1
       EQ.0, NO PRINTING OF DISPLACEMENTS
       EQ.1, PRINT DISPLACEMENTS
    VELOCITY PRINTOUT CODE  . . . . . . . . . . . . (IVC)  =     1
       EQ.0, NO PRINTING OF VELOCITIES
       EQ.1, PRINT VELOCITIES
    ACCELERATION PRINTOUT CODE  . . . . . . . . . . (IAC)  =     1
       EQ.0, NO PRINTING OF ACCELERATIONS
       EQ.1, PRINT ACCELERATIONS

CARD NUMBER 7
    BLOCK  1
      FIRST NODE OF THIS BLOCK  . . . . .  (IPNODE(1,1)) =     1
      LAST NODE OF THIS BLOCK  . . . . . . (IPNODE(2,1)) =     3
1

A N A L Y S I S   T Y P E  (ESTABLISHED USING IMASS,NEGL,NEGNL)
    TIME DEPENDENCY CODE . . . . . . . . . . . . (ISTAT)   =     0
       EQ.0, STATIC ANALYSIS
       EQ.1, DYNAMIC ANALYSIS
    NONLINEARITY CODE  . . . . . . . . . . . . . (KLIN)    =     1
       EQ.0, LINEAR ANALYSIS
       EQ.1, NONLINEAR ANALYSIS
    CORE INFORMATION . . . . (DECIMAL) . .
      REQUESTED CORE=        39
```

OBTAINED . . .

1 N O D A L   P O I N T   D A T A

INPUT NODAL DATA

NODE	BOUNDARY CONDITION CODES						NODAL POINT COORDINATES			MESH GENERATING CODES	
	X	Y	Z	XX	YY	ZZ	X	Y	Z	KN	IT
1	1	1	1	1	1	1	0.0	0.0	0.0	0	
2	0	0	1	1	1	0	1.900	0.0	0.0	0	
3	1	1	1	1	1	1	1.900	-10.000	0.0	0	

GENERATED NODAL DATA

NODE	BOUNDARY CONDITION CODES						NODAL POINT COORDINATES		
	X	Y	Z	XX	YY	ZZ	X	Y	Z
1	1	1	1	1	1	1	0.0	0.0	0.0
2	0	0	1	1	1	0	1.900	0.0	0.0
3	1	1	1	1	1	1	1.900	-10.000	0.0

EQUATION NUMBERS

N	X	Y	Z	XX	YY	ZZ
1	0	0	0	0	0	0
2	1	2	0	0	0	3
3	0	0	0	0	0	0

CORE INFORMATION . . . (DECIMAL) . .
REQUESTED CORE. 45
OBTAINED . . .

1 L O A D   C O N T R O L   D A T A

NUMBER OF LOADS = 2
NUMBER OF LOAD CURVES = 2
MAX NUMBER OF POINTS IN LOAD CURVES = 2
GRAVITY LOADING CODE . . (IOGRAV) = 0
EQ.0, NO GRAVITY LOADING
EQ.1, LUMPED GRAVITY LOADING

1 I N I T I A L   C O N D I T I O N S

INITIAL CONDITIONS CODE (ICON) = 0
EQ.0, ZERO INITIAL CONDITIONS
EQ.1, INITIAL CONDITIONS ARE READ
(BUT RESTART OVER-RIDES ICON)

INITIAL CONDITIONS PRINT-OUT CODE (IPRIC) = 0
EQ.0, PRINT
EQ.1, DO NOT PRINT

1E L E M E N T   G R O U P   D A T A

E L E M E N T   G R O U P .... = 1 (NONLINEAR)

```
STORAGE CHECK FOR ELEMENT GROUP INFORMATION

   CORE INFORMATION . . . (DECIMAL). .
       REQUESTED CORE=        1893
       OBTAINED . . .

E L E M E N T   D E F I N I T I O N

ELEMENT TYPE . . . . . . . . . . . . . .( NPAR(1) ). . =    4
    EQ.1, TRUSS ELEMENTS
    EQ.2, 2-DIM ELEMENTS
    EQ.3, 3-DIM ELEMENTS
    EQ.4, BEAM  ELEMENTS

NUMBER OF ELEMENTS. . . . . . . . . . . .( NPAR(2) ). . =    1

TYPE OF NONLINEAR ANALYSIS. . . . . . . .( NPAR(3) ). . =    1
    EQ.0, LINEAR ELASTIC ONLY
    EQ.1, MATERIALLY NONLINEAR ONLY
    EQ.2, TOTAL LAGRANGIAN FORMULATION

ELEMENT BIRTH AND DEATH OPTIONS . . . . .( NPAR(4) ). . =    0
    EQ.0, OPTION NOT ACTIVE
    EQ.1, BIRTH OPTION ACTIVE
    EQ.2, DEATH OPTION ACTIVE

ELEMENT TYPE CODE . . . . . . . . . . . .( NPAR(5) ). . =    1
     EQ.0, IN PLANE BEAM
     EQ.1, GENERAL 3-D BEAM

INTEGRATION ORDER IN  'R'  DIRECTION. .( NPAR(9) ). . =    5
INTEGRATION ORDER IN  'S'  DIRECTION. .( NPAR(10)). . =    5
INTEGRATION ORDER IN  'T'  DIRECTION. .( NPAR(11)). . =    5

NUMBER OF STRESS OUTPUT TABLES          ( NPAR(13)). . =    0
    EQ.0, PRINT AT ALL INTEGRATION POINTS

MAXIMUM NUMBER OF STRESS OUTPUT LOCATIONS
   IN A TABLE . . . . . . . . . . . . . .( NPAR(14)). . =   16


M A T E R I A L   D E F I N I T I O N

MATERIAL MODEL. . . . . . . . . . . . . .( NPAR(15)). . =    2
    EQ.1,   LINEAR ELASTIC
    EQ.2,  ELASTIC-PLASTIC

NUMBER OF DIFFERENT SETS OF MATERIAL
    CONSTANTS . . . . . . . . . . . . . .( NPAR(16)). . =    1

NUMBER OF MATERIAL CONSTANTS PER SET. .( NPAR(17)). . =    6

S E C T I O N   D E F I N I T I O N

    TYPE   ICS            ISHEAR          DEN
```

```
      1   2   PIPE          0        0.10000+01

 S E C T I O N   P R O P E R T Y
  TYPE       PROP(1)=E      PROP(2)=XNU     PROP(3)=DO     PROP(4)=DI    PROP(5)=SIGY     PROP(6)=ET
    1     0.1200D+04     0.4800D+00     0.3800D+01     0.2500D+01     0.1200D+04     0.0

 E L E M E N T   I N F O R M A T I O N

     N     II     JJ     KK  TYPE   IPS    KG    ETIME
     1      1      2      3     1     1     1       0.

 STORAGE CHECK FOR LOAD INPUT

    CORE INFORMATION . . . (DECIMAL). .
        REQUESTED CORE=          54
        OBTAINED . . .

1TOTAL SYSTEM DATA

     NUMBER OF EQUATIONS . . . . . . . . . . . . . . .(NEQ)   =        3
     NUMBER OF MATRIX ELEMENTS . . . . . . . . . . . .(NWK)   =        6
     MAXIMUM HALF BANDWIDTH . . . . . . . . . . . . . (MA )   =        3
     MEAN HALF BANDWIDTH . . . . . . . . . . . . . . .(MAM)   =        3
     MAXIMUM BLOCK LENGTH . . . . . . . . . . . . . (ISTOH)   =        6
     NUMBER OF BLOCKS . . . . . . . . . . . . . . .(NBLOCK)   =        1

     NUMBER OF COLUMNS PER BLOCK AND 1ST COUPLING BLOCK
       NUMBER OF BLOCK                    1
       NUMBER OF COLUMNS PER BLOCK        3
       FIRST COUPLING BLOCK               1

0**STORAGE CHECK FOR ASSEMBLAGE OF LINEAR MATRICES

    CORE INFORMATION . . . (DECIMAL). .
        REQUESTED CORE=        1870
        OBTAINED . . .

C**STORAGE CHECK FOR LOAD VECTORS INPUT PHASE

    CORE INFORMATION . . . (DECIMAL). .
        REQUESTED CORE=          50
        OBTAINED . . .

1 L O A D   D A T A

     LOAD FUNCTION NUMBER   =    1
```

```
FILE: ADINA     OUTPUT  A   NAVAL POSTGRADUATE SCHOOL

    NUMBER OF TIME POINTS  =    2
    TIME VALUE        FRACTION
       0.0          0.7350D+00
       1.0000C      0.7350D+00

    LOAD FUNCTION NUMBER   =    2
    NUMBER OF TIME POINTS  =    2
    TIME VALUE        FRACTION
       0.0          0.1067D+03
       1.0000C      0.1067D+03

  CONCENTRATED LOADS
      NODE     DIRECTION     LOAD CURVE    LOAD CURVE MULTIPL
 C     2           2             1            0.1000D+01
 6     2           6             2            0.1000D+01

0**STORAGE CHECK FOR TIME INTEGRATION PHASE
    CORE INFORMATION . . . (DECIMAL). .
        REQUESTED CORE=          1907
        OBTAINED . . .

1 I N I T I A L   C O N D I T I O N S

  D I S P L A C E M E N T S
  NODE           X-DISPLACEMENT   Y-DISPLACEMENT   Z-DISPLACEMENT    X-ROTATION    Y-ROTATION    Z-ROTATION
     1              0.0              0.0              0.0              0.0           0.0           0.0
     2              0.0              0.0              0.0              0.0           0.0           0.0
     3              0.0              0.0              0.0              0.0           0.0           0.0
1 P R I N T   O U T   F O R   T I M E   S T E P   1                              ( AT TIME  0.1000D+00 )
     1 EQUILIBRIUM ITERATIONS PERFORMED IN THIS TIME  STEP TO REESTABLISH EQUILIBRIUM
  STIFFNESS REFORMED FOR THIS TIME STEP
  D I S P L A C E M E N T S
  NODE           X-DISPLACEMENT   Y-DISPLACEMENT   Z-DISPLACEMENT    X-ROTATION    Y-ROTATION    Z-ROTATION
     1              0.0              0.0              0.0              0.0           0.0           0.0
     2           -0.2967820-08    0.2000070D-01       0.0              0.0           0.0           0.2100790D-01
     3              0.0              0.0              0.0              0.0           0.0           0.0

  S T R E S S   C A L C U L A T I O N S   F O R   E L E M E N T   G R O U P   1 (BEAMS)
          STRESS   LOCATION
  ELEMENT   R     S     T             SIGMA-R       TAU-RS        TAU-RT
     1      1     1     1 ELASTIC   0.20897D+02    0.0           0.0
     1      1     2     1 ELASTIC   0.21095D+02    0.0           0.0
     1      1     3     1 ELASTIC   0.18741D+02    0.0           0.0
```

1	1	6	1	ELASTIC	0.25205D+02	0.0	0.0
1	1	5	1	ELASTIC	0.16885D+02	0.0	C.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.64576D+01	0.0	C.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.71239D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.57914D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.77901D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.51251D+C1	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.16906D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.18651D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.15162D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.20395D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.13418D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.16906D+02	0.0	C.0
1	[illegible]	[illegible]	4	ELASTIC	-0.18651D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.15162D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.20395D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.13418D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.64576D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.71239D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.57514D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.77903D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.51251D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.20829D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.22978D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.18680D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.25127D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.16551D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.64366D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.71C07D+01	0.0	C.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.57725D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	C.7764[illegible]	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.51084D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.16851D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.18590D+02	0.0	C.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.15113D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.20329D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.13374D+02	0.0	C.0
1	[illegible]	[illegible]	4	ELASTIC	-0.16851D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.18590D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.15113D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.20329D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.13374D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.64366D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.71007D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.57725D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.77649D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.51084D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.2[illegible]965D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.23128D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.1[illegible]C2D+02	0.0	C.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.[illegible]291D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.16639D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.64786D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.71473D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.58102D+01	[illegible]	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.78155D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.51418D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.16[illegible]1D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.18711D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.15211D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.20461D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	-0.13461D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.1[illegible]961D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.18711D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.15211D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.2046[illegible]D+02	0.0	0.0
1	[illegible]	[illegible]	4	ELASTIC	-0.13461D+02	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.64786D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.71473D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.58102D+01	0.0	0.0
1	[illegible]	[illegible]	[illegible]	ELASTIC	0.78155D+01	0.0	0.0
1	[illegible]	[illegible]	5	ELASTIC	0.51418D+01	0.0	0.0

1	4	1	1	ELASTIC	0.20761D+02	0.0	0.0
1	4	2	1	ELASTIC	0.22903D+02	0.0	0.0
1	4	3	1	ELASTIC	0.18619D+02	0.0	C.0
1	4	4	1	ELASTIC	0.25045D+02	0.0	0.0
1	4	5	1	ELASTIC	0.16477D+02	0.0	0.0
1	4	1	2	ELASTIC	0.64156D+01	0.0	0.0
1	4	2	2	ELASTIC	0.70775D+01	0.0	0.0
1	4	3	2	ELASTIC	0.57537D+01	0.0	C.0
1	4	4	2	ELASTIC	0.77355D+01	0.0	0.0
1	4	5	2	ELASTIC	0.50518D+01	0.0	0.0
1	4	1	3	ELASTIC	-0.16796D+02	0.0	C.0
1	4	2	3	ELASTIC	-0.18529D+02	0.0	0.0
1	4	3	3	ELASTIC	-0.15063D+02	0.0	0.0
1	4	4	3	ELASTIC	-0.20262D+02	0.0	0.0
1	4	5	3	ELASTIC	-0.13330D+02	0.0	0.0
1	4	1	4	ELASTIC	-0.16796D+02	0.0	0.0
1	4	2	4	ELASTIC	-0.18529D+02	0.0	0.0
1	4	3	4	ELASTIC	-0.15063D+02	0.0	0.0
1	4	4	4	ELASTIC	-0.20262D+02	0.0	C.0
1	4	5	4	ELASTIC	-0.13330D+02	0.0	0.0
1	4	1	5	ELASTIC	0.64156D+01	0.0	0.0
1	4	2	5	ELASTIC	0.70776D+01	0.0	0.0
1	4	3	5	ELASTIC	0.57537D+01	0.0	0.0
1	4	4	5	ELASTIC	0.77355D+01	0.0	C.0
1	4	5	5	ELASTIC	0.50918D+01	0.0	0.0
1	5	1	1	ELASTIC	0.21033D+02	0.0	0.0
1	5	2	1	ELASTIC	0.23203D+02	0.0	C.0
1	5	3	1	ELASTIC	0.18863D+02	0.0	0.0
1	5	4	1	ELASTIC	0.25373D+02	0.0	0.0
1	5	5	1	ELASTIC	0.16693D+02	0.0	0.0
1	5	1	2	ELASTIC	0.64596D+01	0.0	0.0
1	5	2	2	ELASTIC	0.71702D+01	0.0	0.0
1	5	3	2	ELASTIC	0.58290D+01	0.0	0.0
1	5	4	2	ELASTIC	0.78409D+01	0.0	0.0
1	5	5	2	ELASTIC	0.51584D+01	0.0	C.0
1	5	1	3	ELASTIC	-0.17016D+02	0.0	0.0
1	5	2	3	ELASTIC	-0.18772D+02	0.0	0.0
1	5	3	3	ELASTIC	-0.15261D+02	0.0	0.0
1	5	4	3	ELASTIC	-0.20528D+02	0.0	0.0
1	5	5	3	ELASTIC	-0.13505D+02	0.0	C.0
1	5	1	4	ELASTIC	-0.17016D+02	0.0	0.0
1	5	2	4	ELASTIC	-0.18772D+02	0.0	0.0
1	5	3	4	ELASTIC	-0.15261D+02	0.0	C.0
1	5	4	4	ELASTIC	-0.20528D+02	0.0	0.0
1	5	5	4	ELASTIC	-0.13505D+02	0.0	0.0
1	5	1	5	ELASTIC	0.64996D+01	0.0	0.0
1	5	2	5	ELASTIC	0.71702D+01	0.0	0.0
1	5	3	5	ELASTIC	0.58290D+01	0.0	0.0
1	5	4	5	ELASTIC	0.78408D+01	0.0	0.0
1	5	5	5	ELASTIC	0.51584D+01	0.0	0.0

1 F R I A T C U T F O R T I M E S T E P 2 (AT TIME 0.20000D+00)

1 EQUILIBRIUM ITERATIONS PERFORMED IN THIS TIME STEP TO REESTABLISH EQUILIBRIUM
STIFFNESS REFORMED FOR THIS TIME STEP

D I S P L A C E M E N T S

NODE	X-DISPLACEMENT	Y-DISPLACEMENT	Z-DISPLACEMENT	X-ROTATION	Y-ROTATION	Z-ROTATION
1	0.0	0.0	0.0	0.0	0.0	0.0
2	-0.296782D-08	0.200007D-01	0.0	0.0	0.0	0.210079D-01
3	0.0	0.0	0.0	0.0	0.0	0.0

S T R E S S C A L C U L A T I O N S F O R E L E M E N T G R O U P 1 (BEAMS)

ELEMENT STRESS LOCATION R S T SIGMA-R TAU-RS TAU-RT

1	1	1	1	ELASTIC	0.20897D+02	0.0	0.0
1	1	2	1	ELASTIC	0.23053D+02	0.0	0.0
1	1	3	1	ELASTIC	0.18741D+02	0.0	0.0
1	1	4	1	ELASTIC	0.25209D+02	0.0	0.0
1	1	5	1	ELASTIC	0.16585D+02	0.0	0.0
1	1	1	2	ELASTIC	0.64576D+01	0.0	0.0
1	1	2	2	ELASTIC	0.71239D+01	0.0	0.0
1	1	3	2	ELASTIC	0.57914D+01	0.0	0.0
1	1	4	2	ELASTIC	0.77901D+01	0.0	0.0
1	1	5	2	ELASTIC	0.51251D+01	0.0	0.0
1	1	1	3	ELASTIC	-0.16906D+02	0.0	0.0
1	1	2	3	ELASTIC	-0.18651D+02	0.0	0.0
1	1	3	3	ELASTIC	-0.15162D+02	0.0	0.0
1	1	4	3	ELASTIC	-0.20395D+02	0.0	0.0
1	1	5	3	ELASTIC	-0.13418D+02	0.0	0.0
1	1	1	4	ELASTIC	-0.16906D+02	0.0	0.0
1	1	2	4	ELASTIC	-0.18651D+02	0.0	0.0
1	1	3	4	ELASTIC	-0.15162D+02	0.0	0.0
1	1	4	4	ELASTIC	-0.20395D+02	0.0	0.0
1	1	5	4	ELASTIC	-0.13418D+02	0.0	0.0
1	1	1	5	ELASTIC	0.64576D+01	0.0	0.0
1	1	2	5	ELASTIC	0.71239D+01	0.0	0.0
1	1	3	5	ELASTIC	0.57514D+01	0.0	0.0
1	1	4	5	ELASTIC	0.77902D+01	0.0	0.0
1	1	5	5	ELASTIC	0.51251D+01	0.0	0.0
1	2	1	1	ELASTIC	0.20829D+02	0.0	0.0
1	2	2	1	ELASTIC	0.22576D+02	0.0	0.0
1	2	3	1	ELASTIC	0.18680D+02	0.0	0.0
1	2	4	1	ELASTIC	0.25127D+02	0.0	0.0
1	2	5	1	ELASTIC	0.16531D+02	0.0	0.0
1	2	1	2	ELASTIC	0.64366D+01	0.0	0.0
1	2	2	2	ELASTIC	0.71007D+01	0.0	0.0
1	2	3	2	ELASTIC	0.57725D+01	0.0	0.0
1	2	4	2	ELASTIC	0.77648D+01	0.0	0.0
1	2	5	2	ELASTIC	0.51084D+01	0.0	0.0
1	2	1	3	ELASTIC	-0.16851D+02	0.0	0.0
1	2	2	3	ELASTIC	-0.18590D+02	0.0	0.0
1	2	3	3	ELASTIC	-0.15113D+02	0.0	0.0
1	2	4	3	ELASTIC	-0.20329D+02	0.0	0.0
1	2	5	3	ELASTIC	-0.13374D+02	0.0	0.0
1	2	1	4	ELASTIC	-0.16851D+02	0.0	0.0
1	2	2	4	ELASTIC	-0.18590D+02	0.0	0.0
1	2	3	4	ELASTIC	-0.15113D+02	0.0	0.0
1	2	4	4	ELASTIC	-0.20329D+02	0.0	0.0
1	2	5	4	ELASTIC	-0.13374D+02	0.0	0.0
1	2	1	5	ELASTIC	0.64366D+01	0.0	0.0
1	2	2	5	ELASTIC	0.71007D+01	0.0	0.0
1	2	3	5	ELASTIC	0.57725D+01	0.0	0.0
1	2	4	5	ELASTIC	0.77648D+01	0.0	0.0
1	2	5	5	ELASTIC	0.51084D+01	0.0	0.0
1	3	1	1	ELASTIC	0.20965D+02	0.0	0.0
1	3	2	1	ELASTIC	0.23128D+02	0.0	0.0
1	3	3	1	ELASTIC	0.18802D+02	0.0	0.0
1	3	4	1	ELASTIC	0.25291D+02	0.0	0.0
1	3	5	1	ELASTIC	0.16639D+02	0.0	0.0
1	3	1	2	ELASTIC	0.64726D+01	0.0	0.0
1	3	2	2	ELASTIC	0.71470D+01	0.0	0.0
1	3	3	2	ELASTIC	0.58102D+01	0.0	0.0
1	3	4	2	ELASTIC	0.78155D+01	0.0	0.0
1	3	5	2	ELASTIC	0.51418D+01	0.0	0.0
1	3	1	3	ELASTIC	-0.16561D+02	0.0	0.0
1	3	2	3	ELASTIC	-0.18711D+02	0.0	0.0
1	3	3	3	ELASTIC	-0.15211D+02	0.0	0.0
1	3	4	3	ELASTIC	-0.20461D+02	0.0	0.0
1	3	5	3	ELASTIC	-0.13461D+02	0.0	0.0
1	3	1	4	ELASTIC	-0.16561D+02	0.0	0.0
1	3	2	4	ELASTIC	-0.18711D+02	0.0	0.0
1	3	3	4	ELASTIC	-0.15211D+02	0.0	0.0
1	3	4	4	ELASTIC	-0.20461D+02	0.0	0.0
1	3	5	4	ELASTIC	-0.13461D+02	0.0	0.0
1	3	1	5	ELASTIC	0.64726D+01	0.0	0.0
1	3	2	5	ELASTIC	0.71471D+01	0.0	0.0

1	3	3	5	ELASTIC	0.581020D+01	0.0	0.0
1	3	4	5	ELASTIC	0.781550D+01	0.0	0.0
1	3	5	5	ELASTIC	0.514180D+01	0.0	0.0
1	4	1	1	ELASTIC	0.207610D+02	0.0	0.0
1	4	2	1	ELASTIC	0.225C30D+02	0.0	0.0
1	4	3	1	ELASTIC	0.186190D+02	0.0	0.0
1	4	4	1	ELASTIC	0.250450D+02	0.0	0.0
1	4	5	1	ELASTIC	0.164770D+02	0.0	0.0
1	4	1	2	ELASTIC	0.641560D+01	0.0	0.0
1	4	2	2	ELASTIC	0.707750D+01	0.0	0.0
1	4	3	2	ELASTIC	0.575370D+01	0.0	C.0
1	4	4	2	ELASTIC	0.773950D+01	0.0	0.0
1	4	5	2	ELASTIC	0.505180D+01	0.0	0.0
1	4	1	3	ELASTIC	-0.167960D+02	0.0	0.0
1	4	2	3	ELASTIC	-0.185290D+02	0.0	0.0
1	4	3	3	ELASTIC	-0.15C630D+02	0.0	C.0
1	4	4	3	ELASTIC	-0.202620D+02	0.0	0.0
1	4	5	3	ELASTIC	-0.133300D+02	0.0	0.0
1	4	1	4	ELASTIC	-0.167960D+02	0.0	0.0
1	4	2	4	ELASTIC	-0.185290D+02	0.0	0.0
1	4	3	4	ELASTIC	-0.150630D+02	0.0	0.0
1	4	4	4	ELASTIC	-0.202620D+02	0.0	0.0
1	4	5	4	ELASTIC	-C.133300D+02	0.0	0.0
1	4	1	5	ELASTIC	0.641560D+01	0.0	C.0
1	4	2	5	ELASTIC	0.707760D+01	0.0	0.0
1	4	3	5	ELASTIC	0.575370D+01	0.0	0.0
1	4	4	5	ELASTIC	0.773950D+01	0.0	C.0
1	4	5	5	ELASTIC	0.505180D+01	0.0	0.0
1	5	1	1	ELASTIC	0.21C330D+02	0.0	0.0
1	5	2	1	ELASTIC	0.232030D+02	0.0	0.0
1	5	3	1	ELASTIC	0.188630D+02	0.0	0.0
1	5	4	1	ELASTIC	0.253730D+02	0.0	0.0
1	5	5	1	ELASTIC	0.166930D+02	0.0	0.0
1	5	1	2	ELASTIC	0.649960D+01	0.0	0.0
1	5	2	2	ELASTIC	0.717020D+01	0.0	C.0
1	5	3	2	ELASTIC	0.582900D+01	0.0	0.0
1	5	4	2	ELASTIC	0.784C8D+01	0.0	0.0
1	5	5	2	ELASTIC	0.515840D+01	0.0	0.0
1	5	1	3	ELASTIC	-0.170160D+02	0.0	0.0
1	5	2	3	ELASTIC	-0.187720D+02	0.0	C.0
1	5	3	3	ELASTIC	-0.152610D+02	0.0	0.0
1	5	4	3	ELASTIC	-0.205260D+02	0.0	0.0
1	5	5	3	ELASTIC	-0.135050D+02	0.0	C.0
1	5	1	4	ELASTIC	-0.170160D+02	0.0	0.0
1	5	2	4	ELASTIC	-0.187720D+02	0.0	0.0
1	5	3	4	ELASTIC	-0.152610D+02	0.0	0.0
1	5	4	4	ELASTIC	-0.205280D+02	0.0	0.0
1	5	5	4	ELASTIC	-0.135050D+02	0.0	C.0
1	5	1	5	ELASTIC	0.649960D+01	0.0	0.0
1	5	2	5	ELASTIC	0.717020D+01	0.0	0.0
1	5	3	5	ELASTIC	0.582900D+01	0.0	0.0
1	5	4	5	ELASTIC	0.784080D+01	0.0	0.0
1	5	5	5	ELASTIC	0.515840D+01	0.0	0.0

1 S C L L L T I C A T I M E L O G (IN SEC)

FCR PROBLEM

STATIC ANALYSIS CF A CIRCULAR CROSS-SECTION RUBBER BEAM

INPUT PHASE 0.0

ASSEMBLAGE OF LINEAR STIFFNESS,EFFECTIVE STIFF-
NESS,MASS MATRICES AND LOAD VECTORS 0.0

FREQUENCY ANALYSIS 0.0

TRIANGULARIZATION OF LINEAR (EFFECTIVE)
STIFFNESS MATRIX 0.0

```
STEP-BY-STEP SOLUTION (     2 TIME STEPS)

   CALCULATION OF EFFECTIVE LOAD VECTORS .          0.0
   UPDATING EFFECTIVE STIFFNESS MATRICES
     AND LOAD VECTORS FOR NONLINEARITIES .          0.0
   SOLUTION OF EQUATIONS . . . . . . . . .          0.0
   EQUILIBRIUM ITERATIONS . . . . . . . . .         0.0
   CALCULATION AND PRINTING OF DISPLACE-
     MENTS, VELOCITIES, AND ACCELERATIONS           0.0
   CALCULATION AND PRINTING OF STRESSES .           0.0
                                 STEP-BY-STEP TOTAL       0.0


T O T A L   S O L U T I O N   T I M E (SEC). . .          0.0
```

APPENDIX G

TABULATED DATA

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	$\dot{\alpha}_M$	$\dot{\alpha}_A$
1.1	.5	16.38	.422	.421	6.9	3.0	.6
			.671	.669	10.99	3.5	.8
			.922	.91	15.1	4.2	1.3
			1.171	1.17	19.18	5.0	1.6
			1.421	1.42	23.27	6.0	2.0
			1.64	1.63	26.86	7.0	2.1
			1.87	1.85	30.62	10.0	2.6
			2.12	2.07	34.715	13.0	2.8
1.1	1.0	17.75	.422	.421	7.49	2.5	1.5
			.671	.668	11.91	5.0	2.0
			.922	.917	16.366	6.0	3.0
			1.171	1.161	20.785	7.5	3.4
			1.421	1.41	25.22	8.5	4.1
			1.671	1.64	29.66	10.5	4.8
			1.921	1.87	34.1	13.0	5.7
1.1	2.0	20.5	.422	.421	8.651	3.0	2.89
			.671	.668	13.756	5.5	5.9
			.913	.91	18.88	7.5	4.9
			1.15	1.149	24.01	11.0	8.9
			1.382	1.38	29.13	13.5	10.1
			1.614	1.6	34.256	15.0	12.4

Experimental Test Results
(1 of 16)

D/d	L/D	S(in.)	F(lb.)	F_S(lb.)	M(in-lb)	$\dot{\alpha}_M$	$\dot{\alpha}_A$
1.2	.5	16.5	.422	.421	6.963	.23	.25
			.672	.672	-1.088	.5	.405
			.922	.92	15.213	.5	.556
			1.172	1.17	19.338	.75	.707
			1.422	1.4	23.463	1.0	.845
			1.672	1.67	27.571	1.5	1.01
			1.922	1.92	31.697	2.0	1.159
			2.172	2.17	35.805	2.3	1.31
			2.422	2.42	39.93	2.5	1.46
			2.672	2.667	44.006	3.5	1.61
			2.922	2.913	48.065	4.5	1.76
			3.172	3.16	52.14	5.0	1.91
			3.422	3.403	56.150	6.0	2.05
			3.672	3.645	60.143	7.0	2.2
			3.922	3.888	64.152	7.5	2.35
			4.172	4.126	68.079	8.5	2.49
			4.422	4.365	72.023	9.2	2.63
			4.672	4.601	75.917	10.0	2.78
			4.922	4.832	79.728	11.0	2.92
			5.172	5.059	83.474	12.0	3.05
			5.422	5.272	86.988	13.5	3.18
			5.672	5.504	90.816	14.0	3.32
			5.922	5.720	94.38	15.0	3.45
			6.172	5.917	97.631	16.5	3.57
			6.422	6.135	101.228	17.2	3.7
			6.672	6.345	104.693	18.0	3.83

Experimental Test Results
(2 of16)

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	$\dot{\alpha}_M$	$\dot{\alpha}_A$
1.2	.5	16.5	6.922	6.545	107.993	19.0	3.95
			7.172	6.718	110.847	20.5	4.05
			7.422	6.857	113.141	22.5	4.14
			7.672	7.062	116.523	23.0	4.26
			7.922	7.253	119.675	23.7	4.38
			8.172	7.436	122.694	24.5	4.49
			8.422	7.602	125.433	25.5	4.59
			8.672	7.727	127.496	27.0	4.66
			8.922	7.687	126.836	30.5	4.64
			9.172	7.778	128.337	32.0	4.69

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	$\dot{\alpha}_M$	$\dot{\alpha}_A$
1.2	1.0	18.0	.422	.42	7.596	0.0	.5
			.672	.67	12.096	.5	.9
			.922	.92	16.596	1.0	1.25
			1.172	1.17	21.096	1.5	1.59
			1.422	1.42	25.596	2.0	1.94
			1.672	1.67	30.096	2.5	2.3
			1.922	1.927	34.596	3.5	2.7
			2.172	2.1667	39.091	4.0	2.96

Experimental Test Results
(3 of 16)

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	$\dot{\alpha}_M$	$\dot{\alpha}_M$
1.2	1.0	18.0	2.422	2.412	43.596	5.0	3.31
			2.672	2.657	48.096	6.0	3.65
			2.922	2.9	52.596	7.0	3.99
			3.172	3.141	57.096	8.0	4.33
			3.422	3.379	61.596	9.0	4.67
			3.672	3.61	66.096	10.5	5.01
			3.922	3.829	70.596	12.5	5.35
			4.172	4.056	75.096	13.5	5.69
			4.422	4.281	79.596	14.5	6.03
			4.672	4.491	84.096	16.0	6.44
			4.922	4.681	88.596	18.0	6.72
			5.172	4.875	93.096	19.5	7.06
			5.422	4.991	97.596	23.0	7.39
			5.672	5.141	102.096	25.0	7.74
			5.922	5.323	106.596	26.0	8.08
			6.172	5.449	111.096	28.0	8.42
			6.422	5.589	115.596	29.5	8.76
			6.672	5.658	120.096	32.0	9.1
			6.922	5.671	124.596	35.0	9.44

Experimental Test Results
(4 of 16)

D/d	L/d	S(in.)	F(lb.)	F_s(lb.)	M(in-lb.)	$\dot{\alpha}_M$	$\dot{\alpha}_A$
1.2	2.0	21.0	.422	.42	8.862	.5	1.3
			.672	.67	14.112	1.0	2.23
			.922	.92	19.36	2.5	3.09
			1.171	1.71	24.61	3.0	3.93
			1.422	1.419	29.86	3.5	4.77
			1.672	1.666	35.11	5.0	5.61
			1.922	1.91	40.36	6.5	6.45
			2.172	2.15	45.61	8.0	7.28
			2.422	2.37	50.86	10.0	8.11
			2.672	2.614	56.11	12.0	8.96
			2.922	2.801	61.36	14.5	9.76
			3.172	3.04	66.61	16.5	10.6
			3.422	3.226	71.86	19.5	11.4
			3.672	3.33	77.11	22.5	12.19
			3.922	3.55	82.36	25.0	13.02
			4.172	3.72	87.61	27.0	13.82
			4.422	3.83	92.86	30.0	14.6
			4.672	3.896	98.11	33.5	15.4
			4.922	3.98	103.36	36.0	16.62

Experimental Test Results
(5 of 16)

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	α_M°	α_A°
1.26	.5	17.28	.422	.42	7.292	0	.2
			.672	.67	11.612	1.0	.32
			.922	.92	15.932	1.0	.44
			1.172	1.171	20.252	2.0	.6
			1.422	1.42	24.572	2.0	.67
			1.672	1.67	28.892	2.5	.8
			1.922	1.92	33.212	2.5	.9
			2.172	2.169	37.532	3.0	1.02
			2.422	2.419	41.852	3.0	1.14
			2.672	2.669	46.172	4.0	1.3
			2.922	2.913	50.492	4.5	1.4
			3.172	3.16	54.812	5.0	1.5
			3.422	3.409	59.132	5.0	1.6
			3.672	3.652	63.452	6.0	1.7
			3.922	3.901	67.772	6.0	1.8
			4.172	4.145	72.092	6.5	1.96
			4.422	4.389	76.412	7.0	2.08
			4.672	4.632	80.732	7.5	2.2
			4.922	4.874	85.052	8.0	2.3

Experimental Test Results
(6 of 16)

D/d	L/D	S(in.)	F(lb.)	F_S(lb.)	M(in-lb)	$\dot{\alpha}_M$	$\dot{\alpha}_A$
1.26	.5	17.28	5.172	5.115	89.372	8.5	2.4
			5.422	5.355	93.692	9.0	2.5
			5.672	5.594	98.012	9.5	2.6
			5.922	5.823	102.332	10.5	2.7
			6.172	6.048	106.652	11.5	2.8
			6.422	6.282	110.972	12.0	2.9
			6.672	6.514	115.292	12.5	3.0
			6.922	6.745	119.612	13.0	3.1
			7.172	6.959	123.923	14.0	3.3
			7.422	7.186	128.252	14.5	3.5
			7.672	7.411	132.572	15.0	3.6
			7.922	7.634	136.892	15.5	3.7
			8.172	7.855	141.212	16.0	3.8
			8.422	8.075	145.532	16.5	4.0
			8.672	8.293	149.852	17.0	4.1
			8.922	8.485	154.172	18.0	4.3
			9.172	8.698	158.492	18.5	4.4
			9.422	8.909	162.812	19.0	4.45
			9.672	9.117	167.132	19.5	4.5

Experimental Test Results
(7 of 16)

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	α_M°	α_A°
1.26	.5	17.28	9.922	9.324	171.452	20.0	4.65
			10.172	9.528	175.772	20.5	4.7
			10.422	9.679	180.092	21.5	4.75
			10.672	9.985	184.412	22.0	4.8
			10.922	10.091	188.732	22.5	4.9
			11.172	10.284	193.052	23.0	5.1
			11.422	10.435	197.372	24.0	5.2
			11.672	10.671	201.692	24.5	5.3
			11.922	10.805	206.012	25	5.5
			12.172	10.94	210.332	26.0	5.8
			12.422	11.117	214.652	26.5	5.9
			12.672	11.291	218.972	27.0	6.0
			12.922	11.462	223.292	27.5	6.04
			13.172	11.63	227.612	28.0	6.16
			13.422	11.739	231.932	29.0	6.28
			13.672	11.9	236.251	29.5	6.39
			13.922	12.057	240.572	30.0	6.51
			14.172	12.148	244.892	31.0	6.62
			14.422	12.297	249.212	31.5	6.74
			14.672	12.442	253.532	32.0	6.85

Experimental Test Results
(8 of 16)

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	α°_M	α°_A
1.26	.5	17.28	14.922	12.585	257.852	32.5	6.97
			15.172	12.652	262.172	33.5	7.08
			15.422	12.785	266.492	34.0	7.2
			15.672	12.916	270.812	34.5	7.31
			15.922	12.632	275.132	37.5	7.42

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	α°_M	α°_A
1.26	1.0	18.85	.422	.42	7.957	1.0	.5
			.672	.67	12.667	1.5	.7
			.922	.92	17.38	2.0	1.0
			1.172	1.171	22.092	2.5	1.3
			1.422	1.42	26.805	2.5	1.5
			1.672	1.67	31.517	3.0	1.8
			1.922	1.919	36.23	3.0	2.04
			2.172	2.168	40.942	3.5	2.31
			2.422	2.416	45.655	4.0	2.6
			2.672	2.665	50.367	4.0	2.9
			2.922	2.913	55.080	4.5	3.11
			3.172	3.16	59.792	5.0	3.4

Experimental Test Results
(9 of 16)

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	$\dot{\alpha}_M$	$\dot{\alpha}_A$
1.26	1.0	18.85	3.422	3.403	64.505	6.0	3.7
			3.672	3.645	69.217	7.0	3.9
			3.922	3.893	73.930	7.0	4.2
			4.172	4.131	78.642	8.0	4.4
			4.422	4.379	83.355	8.0	4.7
			4.672	4.621	88.067	8.5	5.0
			4.922	4.861	92.78	9.0	5.3
			5.172	5.093	97.492	10.0	5.5
			5.422	5.331	102.205	10.5	5.8
			5.672	5.568	106.917	11.0	6.1
			5.922	5.793	111.63	12.0	6.6
			6.172	5.989	116.342	14.0	6.6
			6.422	6.203	121.055	15.0	7.0
			6.672	6.429	125.767	15.5	7.1
			6.922	6.62	130.48	17.0	7.4
			7.172	6.84	135.192	17.5	7.7
			7.422	7.059	139.905	18.0	7.9
			7.672	7.254	144.617	19.0	8.1
			7.922	7.468	149.33	19.5	8.4
			8.172	7.654	154.042	20.5	8.7

Experimental Test Results
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D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	α°_M	α°_A
1.26	1.0	18.85	8.422	7.781	158.755	22.5	8.9
			8.672	8.012	163.463	22.5	9.2
			9.172	8.411	172.892	23.5	9.7
			9.422	8.574	177.605	24.5	9.9
			9.672	8.73	182.317	25.5	10.2
			9.922	8.918	187.03	26.0	10.5
			10.172	9.023	191.742	27.5	10.7
			10.422	9.159	196.455	28.5	10.9
			10.672	9.195	201.167	30.5	11.2
			10.922	9.262	205.88	32.0	11.5
			11.172	9.474	210.592	32.0	11.7
			11.422	9.633	215.305	32.5	12.0
			11.672	9.789	220.017	33.0	12.3
			11.922	9.766	224.73	35.0	12.5
			12.172	9.785	229.442	36.5	12.8

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	α°_M	α°_A
1.26	2.0	22.0	.422	.42	9.284	1.0	1.7
			.672	.67	14.784	1.5	1.8
			.922	.92	20.262	2.0	2.4

Experimental Test Results
(11 of 16)

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	α_M°	α_A°
1.26	2.0	22.0	1.172	1.71	25.762	2.5	3.06
			1.422	1.42	31.284	3.0	3.7
			1.672	1.67	36.784	3.5	4.3
			1.922	1.917	42.284	4.0	5.03
			2.172	2.163	47.784	5.0	5.7
			2.422	2.408	53.284	6.0	6.33
			2.672	2.655	58.784	6.5	6.98
			2.922	2.9	64.284	7.0	7.64
			3.172	3.145	69.784	7.5	8.29
			3.422	3.384	75.283	8.5	8.95
			3.672	3.627	80.784	9.0	9.59
			3.922	3.849	86.284	11.0	10.5
			4.172	4.081	91.784	12.0	10.9
			4.422	4.299	97.284	13.5	11.5
			4.672	4.513	102.784	15.0	12.2
			4.922	4.731	108.284	16.0	12.8
			5.172	4.933	113.784	17.5	13.5
			5.422	5.142	119.284	18.5	14.1
			5.672	5.329	124.784	20.0	14.7
			5.922	5.509	130.284	21.5	15.4

Experimental Test Results
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D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	α_M°	α_A°
1.26	2.0	-2.0	6.172	5.681	135.784	23.0	16.0
			6.422	5.82	141.284	25.0	16.6
			6.672	5.997	146.784	26.0	17.3
			6.922	6.139	152.284	27.5	17.9
			7.172	6.273	157.784	29.0	18.5
			7.422	6.395	163.284	30.5	19.1
			7.672	6.434	168.784	33.0	19.6
			7.922	6.489	174.284	35.0	20.3
			8.172	6.439	179.784	38.0	20.8
			8.422	5.743	185.284	47.0	21.2

D/d	L/D	S(in.)	F(in.)	F_s(in.)	M(in-lb)	α_M°	α_A°
1.34	.5	89.33	.376	.376	34.08	0.0	.7
			1.12	1.116	139.92	5.0	2.7
			1.3	1.278	198.84	10.5	3.8
			1.3	1.25	240.24	16.0	4.6
			1.49	1.382	300.96	22.0	5.7
			1.68	1.483	359.88	28.0	6.86
			1.86	1.594	416.4	34.0	7.9
			1.86	1.425	453.480	40.0	8.6

Experimental Test Results
(13 of 16)

D/d	L/D	S(in.)	F(lb.)	F_S(lb.)	M(in-lb)	$\dot{\alpha}_M$	$\dot{\alpha}_A$
1.34	.5	89.33	1.86	1.257	495.360	47.5	9.4
			2.1	1.159	555.120	56.5	10.6
			2.42	.965	625.56	66.5	11.9
			2.42	.626	647.28	75.0	12.4
			2.42	.211	660.6	85.0	12.56

D/d	L/D	S(in.)	F(lb.)	F_S(lb.)	M(in-lb)	$\dot{\alpha}_M$	$\dot{\alpha}_A$
1.34	1.0	91.0		.375	61.44	3.5	2.4
				.559	93.84	5.5	3.6
				.909	184.80	13.0	7.1
				1.05	254.4	20.0	9.7
				1.137	334.8	29.0	12.8
				.917	374.52	35.0	14.3
				.958	422.76	43.0	16.2
				.928	484.560	51.5	18.5
				.734	523.680	60.0	20.0

D/d	L/D	S(in.)	F(lb.)	F_S(lb.)	M(in-lb)	$\dot{\alpha}_M$	$\dot{\alpha}_A$
1.34	.5	94.0		.368	112.30	4.0	9.5
				.924	151.8	8.0	11.7
				1.082	226.440	15.0	17.5
				.868	256.44	21.5	19.8
				.647	300.600	30.0	23.04
				.134	343.56	45.0	26.17

Experimental Test Results
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D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	α_M°	α_A°
1.52	.5	91.0	.747	.74	106.66	5.0	1.3
			1.490	1.474	201.498	8.5	2.3
			2.047	1.968	309.184	16.0	3.5
			2.604	2.439	393.121	20.5	4.4
			2.790	2.475	459.784	27.5	5.2
			3.347	2.691	569.80	36.5	6.4
			3.533	2.584	625.7	43.0	7.1
			3.533	2.271	663.8	50.0	7.5
			4.647	2.393	805.0	59.0	9.1
			5.019	1.880	870.0	68.0	9.8
			6.690	.408	1053.0	86.5	11.8

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	α_M°	α_A°
1.52	1.0	93.0	.376	.373	86.55	6.5	2.0
			1.119	1.098	191.01	11.0	4.4
			1.490	1.440	256.51	15.0	5.8
			1.862	1.749	329.07	20.0	7.5
			2.233	1.990	411.00	26.5	9.3
			2.233	2.11	432.01	29.5	9.8
			2.419	1.95	496.0	36.5	11.2
			2.976	2.176	587.55	43.0	13.3

Experimental Test Results
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D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	$\dot{\alpha}_M$	$\dot{\alpha}_A$
1.52	1.0	93.0	3.162	2.03	643.19	50.0	14.5
			3.719	2.02	728.0	57.0	16.4
			4.09	1.73	793.0	65.0	17.9
			4.647	1.28	870.0	74.0	20.0

D/d	L/D	S(in.)	F(lb.)	F_s(lb.)	M(in-lb)	$\dot{\alpha}_M$	$\dot{\alpha}_A$
1.52	2.0	97.0	.433	.40	62.0	7.5	3.0
			1.304	1.286	233.95	13.5	10.7
			1.304	1.233	274.34	19.0	12.5
			1.486	1.358	325.05	24.0	15.0
			1.675	1.466	372.63	29.0	17.0
			1.861	1.477	432.61	37.5	20.0
			1.865	1.316	463.74	45.0	21.0
			2.04	1.199	510.83	54.0	23.0
			2.418	.945	550.18	67.0	25.0
			2.418	.5496	695.49	76.0	32.0
			3.34	.000	795.9	90.0	36.0

Experimental Test Results
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Critical Values for σ

ADINA was used to evaluate the critical stresses in the model. Where the correlation between computer model and experimental model was good in the linear response range, critical stress was taken at 5, 10, and 15 degrees of rotation. Where correlation was poor only the critical stress at the first loading was taken.

D/d	L/D	$_c$(p.s.i.)
1.1	.5	12.27
	1.0	21.27
	2.0	26.97 (5 degrees)
		46.93 (10 degrees)
		66.76 (15 degrees)
1.2	.5	5.565
	1.0	6.27
	2.0	33.047 (5 degrees)
		47.68 (10 degrees)
		59.57 (15 degrees)
1.26	.5	4.36
	1.0	4.798
	2.0	33.46 (5 degrees)
		56.63 (10 degrees)
		68.0 (15 degrees)

D/d	L/D	$_{c}$(p.s.i.)
1.34	.5	13.7
	1.0	24.96
	2.0	62.91
1.52	.5	25.37
	1.0	20.65
	2.0	15.24

APPENDIX H

SAMPLE CALCULATION

I. Piling Size Selection

Assume 6" OD. Steel Pipe

II. Use Appendices B and C to extract environmental loads

Assume a 2 knot current

20 mile/hour wind

Assume 15 feet of water depth

12 feet of piling above water

9 sq. feet of Navigational Package Sail Area

From Appendices B and C

2 knot current acting on 6" pile = 54.41 lbf.

20 mile/hour wind acting on 6" pile = 3.65 lbf.

20 mile/hour wind acting on 9 sq. feet sail area

= 10.94 lbf.

III. Calculate Total Moment

a) 54.41 lbf x 7.5 ft. = 408.075 ft-lb

b) 3.65 lbf x 21 feet = 76.65 ft-lb

c) 10.94 lbf x 30 feet = 328.2 ft=lb

Total Moment <u>812.925 ft-lb</u> = <u>9755.1 in-lb</u>

IV. Using the critical value for σ

$\sigma_c = 68$ p.s.i. and $\sigma_c = \frac{MC}{I}$

Solving for D and d where D = 1.26 d (the ratio for the desired snap-through action).

V. D = 13.38 inches

d = 10.44 inches

VI. Final Size

Using the 2-1 ratio L/D

L = 26.76 inches

D = 13.38 inches

d = 10.44

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